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SHAPED CHARGE JET BREAKUP STUDIES USING  
RADIOGRAPH MEASUREMENT AND SURFACE  
INSTABILITY CALCULATIONS

Prepared by

Dyna East Corporation  
Wynnewood, PA 19096

April 1977

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numerical study of the effects of yield strength, inertia forces, surface disturbance wavelength, and irregular or "random" surface disturbances is presented. Results indicate that high yield strength and low density jet materials will both cause earlier breakup. A critical range of disturbance wave-lengths exists in shaped charge jets; if a random surface disturbance is imposed, a critical wavelength will prevail and eventually cause the jet to breakup into segments with lengths approximately equal to experimentally measured values.

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## I. INTRODUCTION

In recent years, tremendous advances have been made in the basic understanding of shaped charge mechanics. These include the processes of liner collapse, jet formation, and formulas for jet radius and strain. Both two-dimensional computer codes and one-dimensional modeling have been used successfully for the analysis of shaped charges. One important area, however, has not been well understood and cannot be simulated easily by computer methods. This area is the breakup of the shaped charge jet. This breakup, or segmentation, occurs in all jets that have a large velocity gradient with higher speeds at the tip and lower speeds near the tail. This process can be seen in Fig. 1 which shows flash radiographs of a typical shaped charge jet at three successive times, displayed in the proper position-time coordinates. At the earliest time the jet segmentation has begun near the tip; most of the jet is still continuous. The later times show the completely segmented jet.

In [1] and [2], we have presented initial studies on the jet breakup phenomenon. Let us now briefly review the results of these initial studies. Formulas for the strain and radius of shaped charge jets based on a one-dimensional model are presented in [1]. Further, in [1] and [2], a method to determine the jet breakup time distribution from timed flash jet radiographs was developed. This method was then applied to jets from a series of identical BRL 81.3mm standard 42° copper-lined charges and an unconfined 105mm 42° copper lined charge in [1]. Despite the scatter in the results, the breakup time does show a definite "trend" as is indicated in [1]. In fact, for the particular charge studied, the trend indicates that the jet breaks first near the tip with a progressively increasing breakup time towards the tail. Thus, shaped charge jets do not necessarily break simultaneously along their length, as assumed previously by some investigators. The resulting jet breakup time distribution was then contrasted to the one-dimensional theoretical jet strain and radius distributions. This is presented in [1] and [2] where it is concluded that, for copper liners, the breakup time distribution is related to the jet radius distribution. No other correlation was indicated in [1] or [2].

The present study addresses the problem of jet breakup through the use of two approaches: (1) triple-flash radiographs of various jets to determine jet velocity, breakup time, etc., and (2) surface instability as a cause of breakup.

The first approach is actually an extension or continuation of the work we have presented in [1]. The method of [1] to measure breakup time, jet velocity, etc. from timed flash radiographs is applied here to many jets from various shaped charges having different cone angles, different liner wall thicknesses, liners with tapered walls, different liner materials, and light or heavy confinement. This approach has enabled us to obtain many characteristics of jets from a large cross-section of shaped charges. The data from all of these charges are

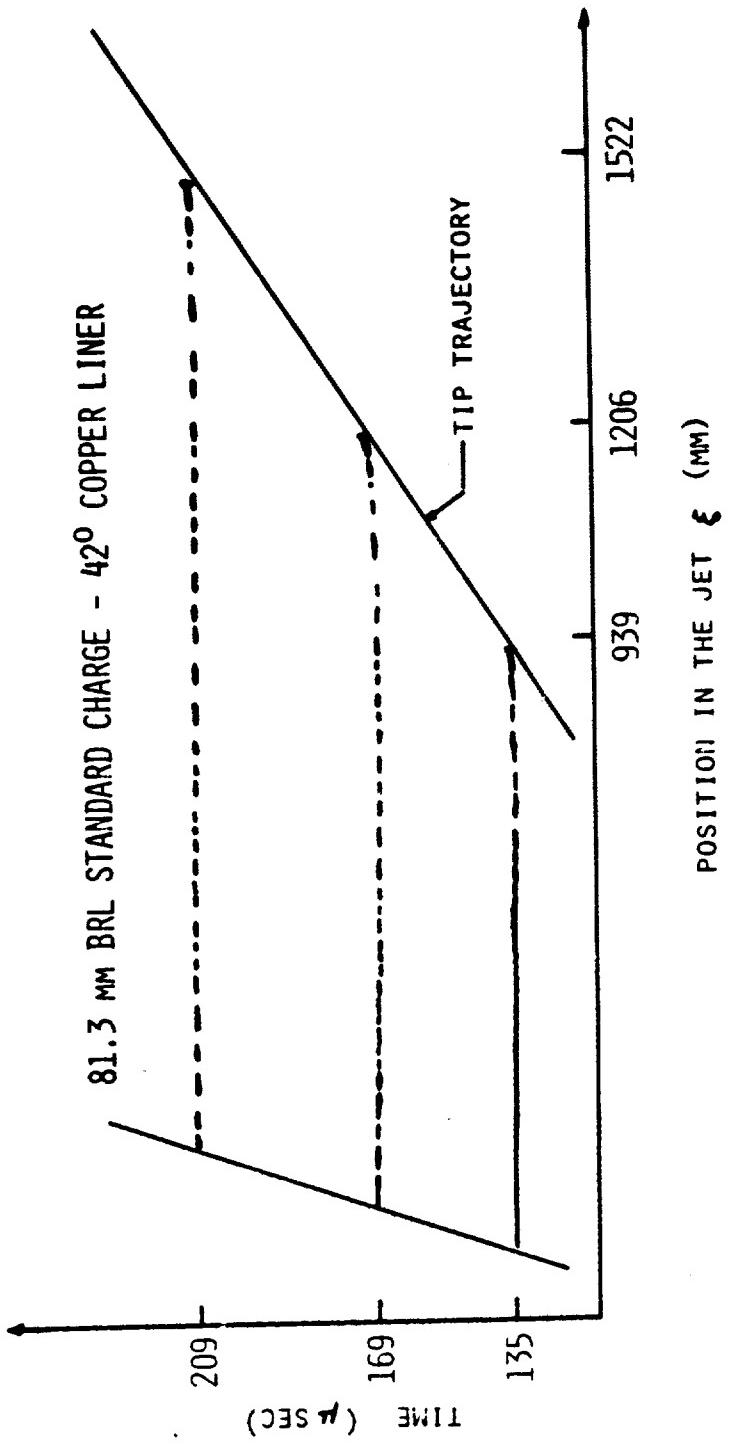


FIGURE 1. Radiographs showing the jet breakup phenomenon.  
(Radiographs courtesy of R. Jameson, BRL)

conveniently tabulated and graphically displayed in this report. The geometry of the charges studied are given in Appendix A. The measured jet velocity, breakup time and jet radius are plotted graphically in Appendix B. Appendix C contains a tabular list of this data and in addition includes the aspect ratio of the jet segments and difference in velocity between neighboring particles. All of this data has been analyzed to obtain trends in the breakup phenomenon. The breakup trends have been contrasted with the one-dimensional strain and radius predictions using the formulas of [1]. Within an individual jet no general correlation has been observed between breakup time and one-dimensional parameters. The results of the breakup time measurements of all copper jets studied, however, do exhibit a definite trend. This trend yields a semi-empirical design curve for breakup time which can be used in conjunction with a one-dimensional shaped charge model to predict breakup time for copper jets. This first approach is presented in Section II.

The second approach involves the study of the instability caused by various disturbances in the jet with the goal of determining whether or not this instability may cause the jet to breakup. We know from classical hydrodynamics that a continuous liquid jet will break into small segments because of surface instability. The breakup of a shaped charge jet resembles this very much, and our study shows that the shaped charge jet is indeed subject to surface instability. In principle, there are three forces which may cause this instability: surface tension, aerodynamic force, and material strength (elastic-plastic force) in the jet. Both analytical studies and two-dimensional finite-difference numerical calculations were made, and the results indicate that material strength is the main cause for shaped charge jet instability and breakup. In addition, the effect of strain-rate, time of disturbance initiation, and inertia were considered. The results of this stability study are discussed in Section III. Finally, general conclusions are stated in Section IV.

We would like to note that the results presented in this report summarize the work conducted during the entire contract period. Some of these results were presented previously in quarterly progress reports.

## II. JET RADIOGRAPH DATA

The results which we presented in [1] indicate that the measurement of jet radiographs provides an efficient and useful procedure to obtain breakup data. Also breakup trends are indicated in [1] which warrant further investigation. In this study, we have therefore continued using this approach to study jets from a large number of charges having different geometries and liner materials.

### A. General Approach

The detailed development and equations for the computation of breakup time, jet velocity, etc. from the radiograph measurements are given in [1]. Here, we will give only a brief description of this method. Figure 2 shows the position-time plot of two typical neighboring jet segments labeled as K and K+1. Suppose we have radiographs of these two segments at times  $t_1$  and  $t_2$  as indicated in Figure 2. (Note: in the actual case, we have analyzed three timed flash radiographs, as supplied by BRL). We may then compute the velocity of each segment by measuring how far the segments have traveled during the time  $t_2-t_1$ . In the two radiographs the segments are separated by a gap as shown. Under the assumption that the segments remain at constant length and constant velocity after breakup (which is a good approximation after the jet is completely broken as evidenced by the radiographs), it is a simple matter to trace back the front of segment (K+1) and the rear of segment K until they meet, i.e. the gap becomes zero. The time of this meeting  $t_b$  is the breakup time of segment K from segment (K+1). This procedure may be applied successively to each pair of particles, i.e. K and (K+1), (K+1) and (K+2), etc., until the complete breakup time distribution is obtained. There is a certain degree of approximation to this procedure. Since the particles do not break successively from one end of the jet to the other, we sometimes have the situation where a larger segment breaks from the main jet, continues to stretch, and then finally breaks into smaller, constant velocity, constant length segments. However, the time between the initial break and the succeeding breaks is small, therefore the procedure may still be applied approximately to this breakup situation. The resulting breakup times have been found to be within the accuracy of the experimental procedures.

This method of determining the breakup time was then applied to jet radiographs from many various shaped charges. These radiographs were obtained from BRL through the courtesy of R. Jameson, R. Karpp, J. Simon and J. Majorus. For convenience, the different charges are listed in Table I; the detailed geometry and drawings of each are given in Appendix A. It can be seen from this table that we have studied the effects of cone angle, wall thickness, wall taper, and liner material on the breakup mechanism.

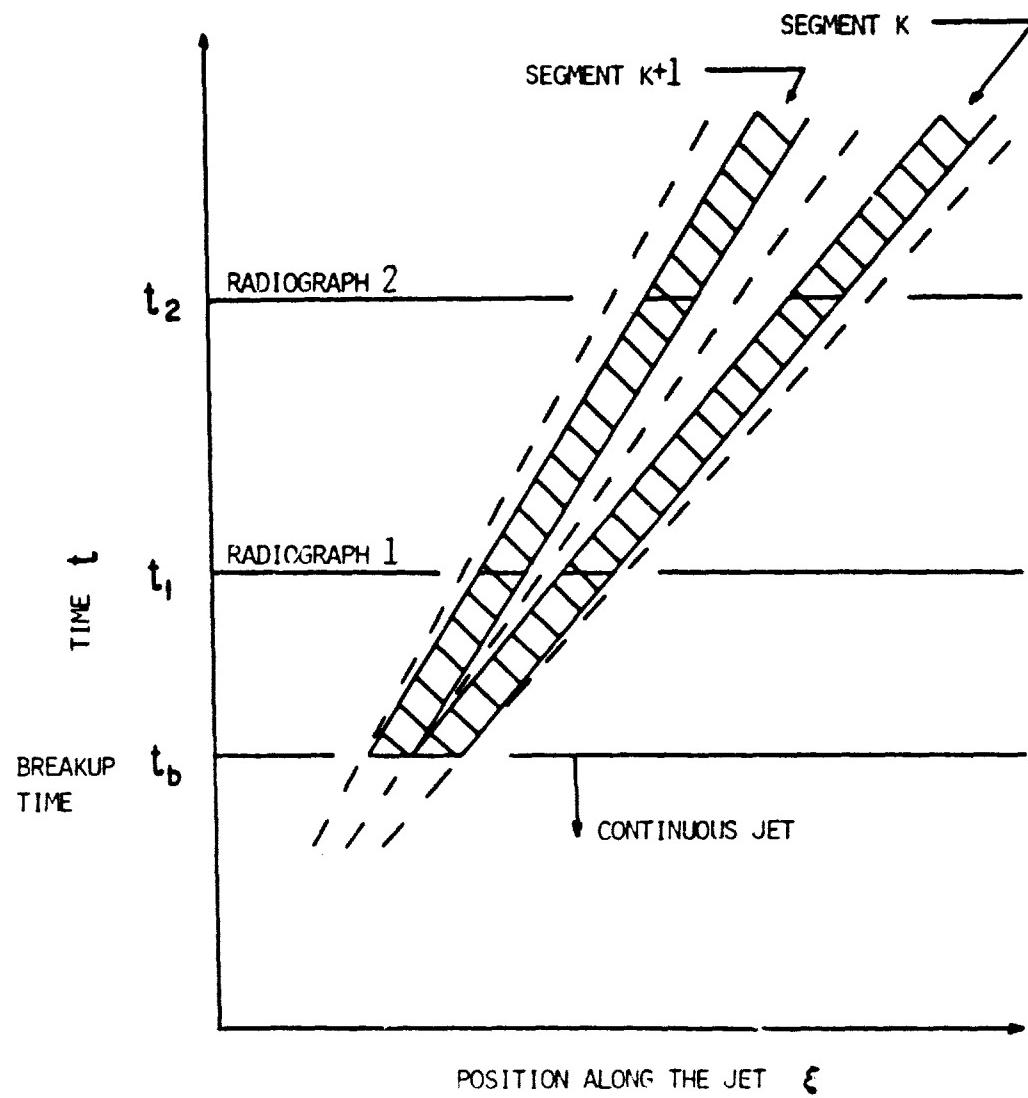


FIGURE 2. Position-time plot of two typical jet segments showing the method of determining the breakup time from jet radiograph measurements.

Table I

List of Charges Examined\*

Copper Lined

Charge No.	Cone Angle	Diameter mm	Wall Thickness mm
1	20°	38.1	1.168
2	40°	38.1	1.168
3	60°	38.1	1.168
4	90°	38.1	1.168
5	42°	50.8	0.762
6	42°	50.8	1.524
7	42°	50.8	2.540
8	42°**	81.3	tapered wall

Aluminum Lined

Charge No.	Cone Angle	Diameter mm	Wall Thickness mm
9	40°	38.1	1.626
10	60°	38.1	1.626
11	90°	38.1	1.626

\* Note that we have also performed a breakup study of jets from the BRL Standard 81.3mm charge and the 105mm unconfined charge in [1].

\*\* Angle of inside wall

### B. Results of Radiograph Measurements

From the measurements of the jet radiographs, we have determined the jet velocity, jet breakup time, and jet radius distributions for all of the charges listed in Table I. Plots of all of the data obtained are given in Appendix B. Figure B1 shows the jet velocity distribution along the length of the jet at a particular time for the series of 31.8mm copper lined charges having cone angles of 20°, 40°, 60° and 90° (Charge Nos. 1-4). Test results of these charges were first reported in [3], where the average breakup time of the complete jet was given. The time base used in all of the present studies is given as  $t = 0$  when the detonation wave reaches the apex of the cone.\* From Fig. B1 we see that, for a given liner material, the tip velocity of the jet decreases as the cone angle increases. It should be noted that, for the 20° copper cone, the resulting jet possessed a bifurcated region at the tip portion. We therefore made our radiograph measurements starting from the first fully coherent particle of the jet, which has a velocity of 8.4mm/usec, much smaller than 9.9mm/usec reported in [3]. We should further note that it has been determined that this bifurcated region is caused by supersonic flow in the jet formation region (See [4] for details). None of the other charges examined under this study possessed this bifurcated region.

The jet velocity distributions for the remaining charges are shown in Figures B2-B6. It is interesting to note that Fig. B6 indicates that the 81.3mm tapered wall charge studied here has a higher jet velocity (8.3 km/sec at the tip) than the 81.3mm standard charge with constant wall thickness studied in [1] (7.9 km/sec at the tip). This somewhat surprising result has a fairly simple explanation. Because of the wall taper (thicker at the cone apex tapering linearly toward the cone base), as we proceed from the apex toward the base the liner elements reach higher collapse velocity than corresponding elements of the charge with a constant wall thickness. This effect provides the tapered wall liner with an overall decrease in the collapse angle (i.e. the angle of the collapsing liner with the charge axis, denoted as  $\beta$  in [1]). From the basic one-dimensional jet formation theory [5] a decrease in collapse angle, in general, produces a higher jet velocity. Finally, from Figs. B1-B6 we also observe that the velocity distribution for each of the charges studied is approximately a straight line.

Plots of the breakup time of the jet particles versus their position in the jet at a particular time for the eleven charges examined are given in Figs. B7-B17. The scatter in the results is to be expected because of the nature of the breakup mechanism. In all cases a definite trend in breakup time exists. To demonstrate this trend, a straight line was passed through the data using the method of least squares. This line is also shown in Figs. B7-B17. All of the jets studied exhibit trends which indicate that the tip portion breaks earlier than the rear portion except for the 38.1mm, 40° copper charge (Charge No.2) and the 81.3mm, 42° copper tapered wall

\* Except for the data which is tabulated in Appendix C: The data there is based on the initiation time of the main explosive charge. See Appendix C for details.

charge (Charge No.8). Breakup trends for these two charges show that these jets breakup almost simultaneously. Note that since only part of the jet for each charge appeared in the radiographs, these conclusions are only valid for the portion of the jets measured.

Next, the measured jet radius distributions for the eleven charges studied are given in Figures B18-B28. We see from Figs. B18-B21 that for copper lined charges of a given diameter and wall thickness the average jet radius increases with increasing cone angle. This effect is not so pronounced in the case of the aluminum lined charges as can be seen from Figs. B22-B24. Further, we note from Figs. B25-B27 that, all else being equal, relatively large increases in wall thickness give only small increases in jet radius.

Finally, all of the data resulting from the radiograph measurements are tabulated in Appendix C. In addition to the jet velocity, breakup time, and jet radius, which were graphically displayed in Appendix B, we have also tabulated the aspect ratio (length to diameter,  $l/d$ ) of each segment and the jet velocity difference between neighboring segments  $\Delta V_j$ . The average  $l/d$  and average  $\Delta V_j$  are summarized in Tables II and III. In these tables, we have also summarized this data for the BRL Standard 81.3mm and 105mm unconfined charges which were studied in [1]. Since there was a certain amount of scatter in these quantities, the coefficient of variation (standard deviation divided by the mean) in each case was also computed. From Table II we see that the average  $l/d$  varies between 4 and 6 for copper lined conical charges of constant wall thickness. The tapered wall cone has an  $l/d$  ratio of 3.3 which may indicate that, even though this charge has a higher tip velocity than the corresponding constant wall charge, its penetration performance at longer standoffs may be poorer because of the small segment size and early breakup time. The aluminum lined charges studied have average  $l/d$  ratios of 3.89, 4.92, and 8.39.

From Table III we observe that the overall average velocity difference between neighboring segments for the copper lined charges is approximately 110m/sec. Recently, Held [6] has published that the average  $\Delta V_j$  for the copper lined German charges he studied was approximately 100m/sec. For the aluminum lined charges studied here, we found an overall average  $\Delta V_j$  of 145m/sec. Finally, we obtained radiographs of a copper lined French charge, the ISL "S2T", from Perez [7] and found the average  $l/d$  to be 5.62 and the average  $\Delta V_j$  to be 137m/sec. Data of this nature is useful in obtaining rough estimates of the number of jet segments in newly designed charges.

### C. Comparison of Data with Theory

In [1] and [8] an improved one-dimensional theoretical shaped charge model was developed. This improved model is based on the classical Pugh-Eichelberger-Rostoker [5] theory but uses a semi-empirical collapse formula to describe the explosive-metal interaction process. Further, formulas for jet strain and jet radius were

Table II  
Average Aspect Ratio ( $l/d$ ) of Jet Segments

Copper Lined

Charge No.	Geometry (Dia., Cone Angle, Wall Thk.)	$l/d$ (Average)	Coeff. of Variation
1	38.1 mm, 20°, 1.168 mm	4.69	.520
2	38.1 mm, 40°, 1.168 mm	5.95	.411
3	38.1 mm, 60°, 1.168 mm	5.91	.447
4	38.1 mm, 90°, 1.168 mm	4.49	.301
5	50.8 mm, 42°, 0.762 mm	4.18	.412
6	50.8 mm, 42°, 1.524 mm	4.48	.361
7	50.8 mm, 42°, 2.540 mm	4.48	.336
8	81.3 mm, 42°, tapered	3.31	.417
*	81.3 mm, 42°, 1.905 mm	5.93	.375
*	86.4 mm, 42°, 2.921 mm	5.21	.324
Average $l/d$ for all copper jets		4.86	
C.V.		.180	

Aluminum Lined

Charge No.	Geometry (Dia., Cone Angle, Wall Thk.)	$l/d$	Coeff. of Variation
9	38.1 mm, 40°, 1.626 mm	3.89	.454
10	38.1 mm, 60°, 1.626 mm	4.92	.420
11	38.1 mm, 90°, 1.626 mm	8.39	.426
Average $l/d$ for all Al jets		5.73	
C.V.		.411	

\* These charges were studied in [1] and this data is included here for completeness

Table III

Average Jet Velocity Difference Between Neighboring Segments ( $\Delta V_j$ )Copper Lined

Charge No.	Geometry (Dia., Cone Angle, Wall Thk.)	$\Delta V_j$ (m/sec)	Coeff. of Variation
1	38.1 mm, 20°, 1.168 mm	106	.474
2	38.1 mm, 40°, 1.168 mm	111	.367
3	38.1 mm, 60°, 1.168 mm	135	.335
4	38.1 mm, 90°, 1.168 mm	109	.344
5	50.8 mm, 42°, 0.762 mm	110	.497
6	50.8 mm, 42°, 1.524 mm	115	.522
7	50.8 mm, 42°, 2.540 mm	119	.449
8	81.3 mm, 42°, tapered	108	.519
*	81.3 mm, 42°, 1.905 mm	96	.557
*	86.4 mm, 42°, 2.921 mm	113	.445
Average $\Delta V_j$ for all copper jets		112	
C.V.		.090	

Aluminum Lined

Charge No.	Geometry (Dia., Cone Angle, Wall Thk.)	$\Delta V_j$ (m/sec)	Coeff. of Variation
9	38.1 mm, 40°, 1.626 mm	143	.362
10	38.1 mm, 60°, 1.626 mm	130	.528
11	38.1 mm, 90°, 1.626 mm	162	.154
Average $\Delta V_j$ for all Al jets		145	
C.V.		.111	

\* These charges were studied in [1] and this data is included here for completeness.

developed for this model. Since the publication of [1] and [8], we have improved this model further by incorporating the effect of liner acceleration during collapse. This enables the prediction of the inverse jet velocity gradient region during formation.

This improved one-dimensional model was applied to the eleven charges studied here. In Figs. B1-B6 the theoretical jet velocity distribution of each charge is shown in contrast to the experimental data. We see that excellent agreement is obtained between theory and experiment. Note that in Fig. B4 and B5 there is some discrepancy between the experimental tip velocity and the tip velocity predicted by the theory for Charge Nos. 6 and 7. This prediction could be improved by using a different value for the acceleration. At present, the acceleration values used in all the cases are given by a simple empirical formula which depends only on liner density and thickness. For these two particular charges the liner thickness to liner diameter ratio is much higher than the other charges studied and therefore this simple acceleration formula may be inaccurate for these two charges. Theoretical jet radius distributions were also computed from the one-dimensional model at the breakup times  $t_b$ . The  $t_b$  lines in Figs. B7-B17 were used. As shown in Figs. B18-B28, the theoretical radius distributions compare reasonably well with experimental values.

We next compared the breakup time distribution with the theoretical distribution of other jet properties. The goal here was to find some correlation among these distributions which would indicate controlling parameters in the breakup mechanism. We compared trends in the following properties to the breakup trend: jet strain  $\eta$ , jet radius  $r_j$ , and jet strain rate  $\dot{\eta}$ . The quantities  $\eta$  and  $r_j$  are defined in [1], and  $\dot{\eta}$  is simply the first time derivative of  $\eta$  defined there. We also contrasted these properties to the amount of time elapsed from the formation of an element until it breaks up. This quantity is the absolute breakup time minus the absolute time when the element is first formed, and is denoted  $t_b - t_f$ . The quantity  $t_b$  is from the experimental least squares line and the quantity  $t_f$  is computed from the one-dimensional model.

Since the quantities jet strain, jet radius, and jet strain rate before breakup are continuously changing with time, it is appropriate to compare the breakup time of each segment with these quantities at the time when each segment breaks up. To do this, we first trace back each segment in the radiograph to its original position in the cone,  $x$ , using the one-dimensional model. We are then able to compute  $\eta$ ,  $r_j$ , and  $\dot{\eta}$  of the segment at its own particular breakup time from the least squares experimental trend. Figure 3 shows a plot of  $\eta$ ,  $r_j$ ,  $\dot{\eta}$ ,  $t_b$  and  $t_b - t_f$  versus  $x/h$  for the 38.1mm, 60° copper charge (Charge No.3). Note that  $x$  denotes the original liner position and  $h$  denotes the original height of the cone. Also plotted in Fig. 3 is  $r_j$  at  $t = 55$  usec which is a time before any breakup has occurred.

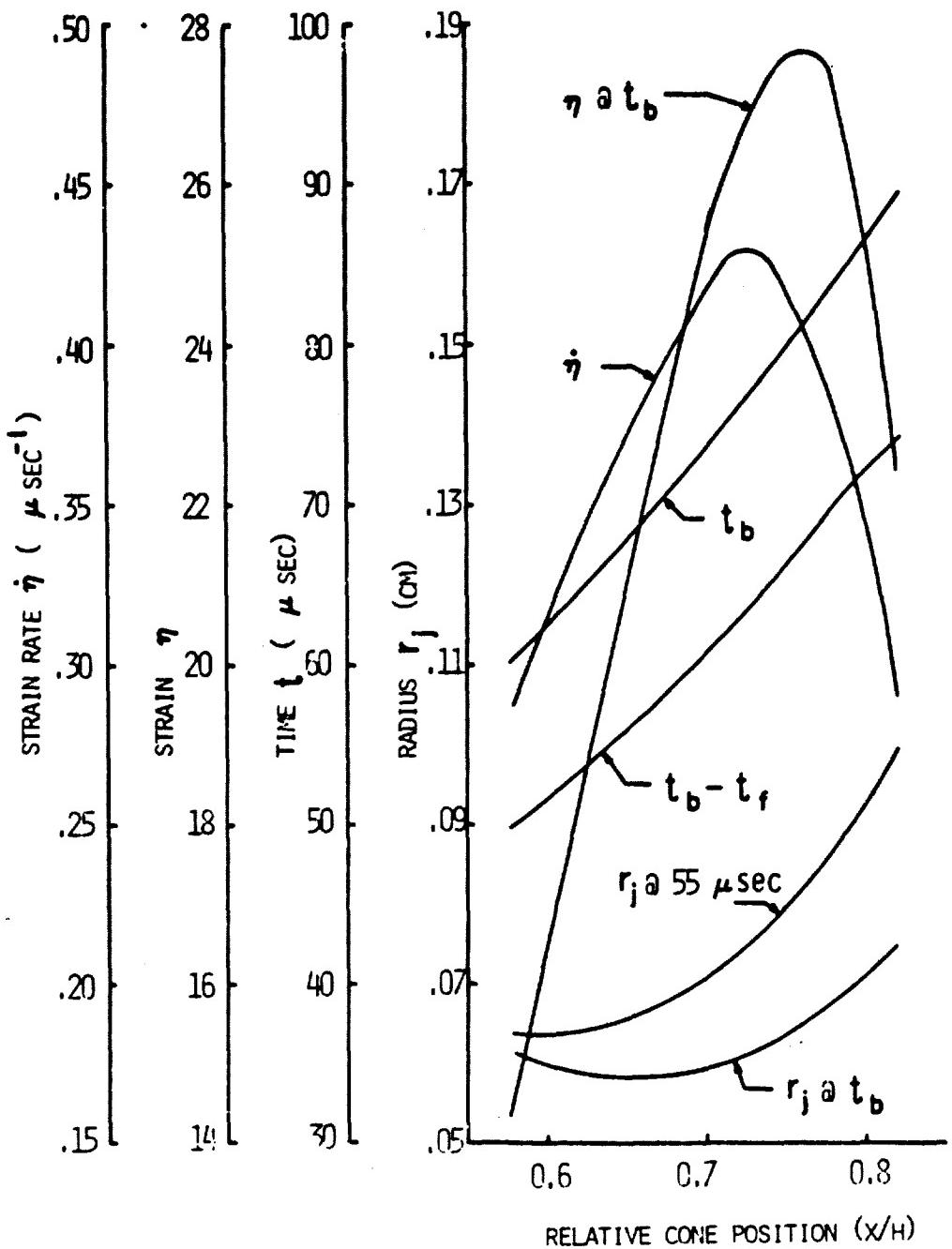


FIGURE 3. Theoretical jet strain-rate, strain, radius and experimental breakup time vs. relative cone position for the 38.1mm,  $60^\circ$  Cu charge. (Charge No. 3)

Figure 3 indicates that there is no reasonable correlation between the breakup time distribution and  $n$  at  $t_b$  or  $\dot{n}$  at  $t_b$ . Both the  $r_j$  at  $t_b$  and  $r_j$  at 55 usec appear to follow the general trend of the breakup time. Plots similar to Figure 3 for the remaining 10 charges were also plotted but are not presented here in the interest of space\*. However, the results indicate that within one jet even  $r_j$  at  $t_b$  and  $r_j$  at a time before breakup may not follow the trend of breakup time. Results do indicate that for copper lined charges  $r_j$  at a time before breakup seems to increase as the breakup time increases but no general conclusion may be drawn.

We next looked at the breakup data from all the copper lined charges together rather than just throughout a single jet. In Fig. 4 we have made a plot of  $t_b-t_f$  vs.  $r_j$  at  $t_b$  for all of the copper lined charges studied here (Charge Nos. 1-8). Also, in Fig. 4, we have plotted the data for the 81.3mm BRL Standard Charge and the 105mm unconfined charge studied in [1]. Three data points were selected from each jet. With the exception of one charge, the 38.1mm, 90° copper (Charge No.4), all of the data points for  $t_b-t_f$  fall within a narrow region monotonically increasing with increasing  $r_j$ . We may speculate that the 90° charge does not fall in this region because the low collapse velocities in a charge with a large cone angle results in lower pressures and velocities at the stagnation point during formation. Therefore, the properties of this jet may be different from those of smaller angle cones. Figure 4 indicates a correlation between the two quantities for the other charges however. In fact, if we draw a line through these points, we obtain a useful breakup time vs. radius curve, which can be used for design purposes. For example, suppose we design a new copper lined charge and wish to obtain its breakup time distribution. We can compute the radius of the elements of the jet as functions of time. If we then plot the radius vs. time curve of a particular jet element on the breakup time vs. radius coordinates, we find that this curve will intersect the breakup curve. This intersection gives the breakup time of that element. We then repeat this procedure for a series of jet elements. This then yields a breakup time distribution for the new charge. This breakup time information may then be used together with other information on a penetration analysis to evaluate the final performance of the new design.

\* These plots for the remaining 10 charges may be found in [9] and [10].

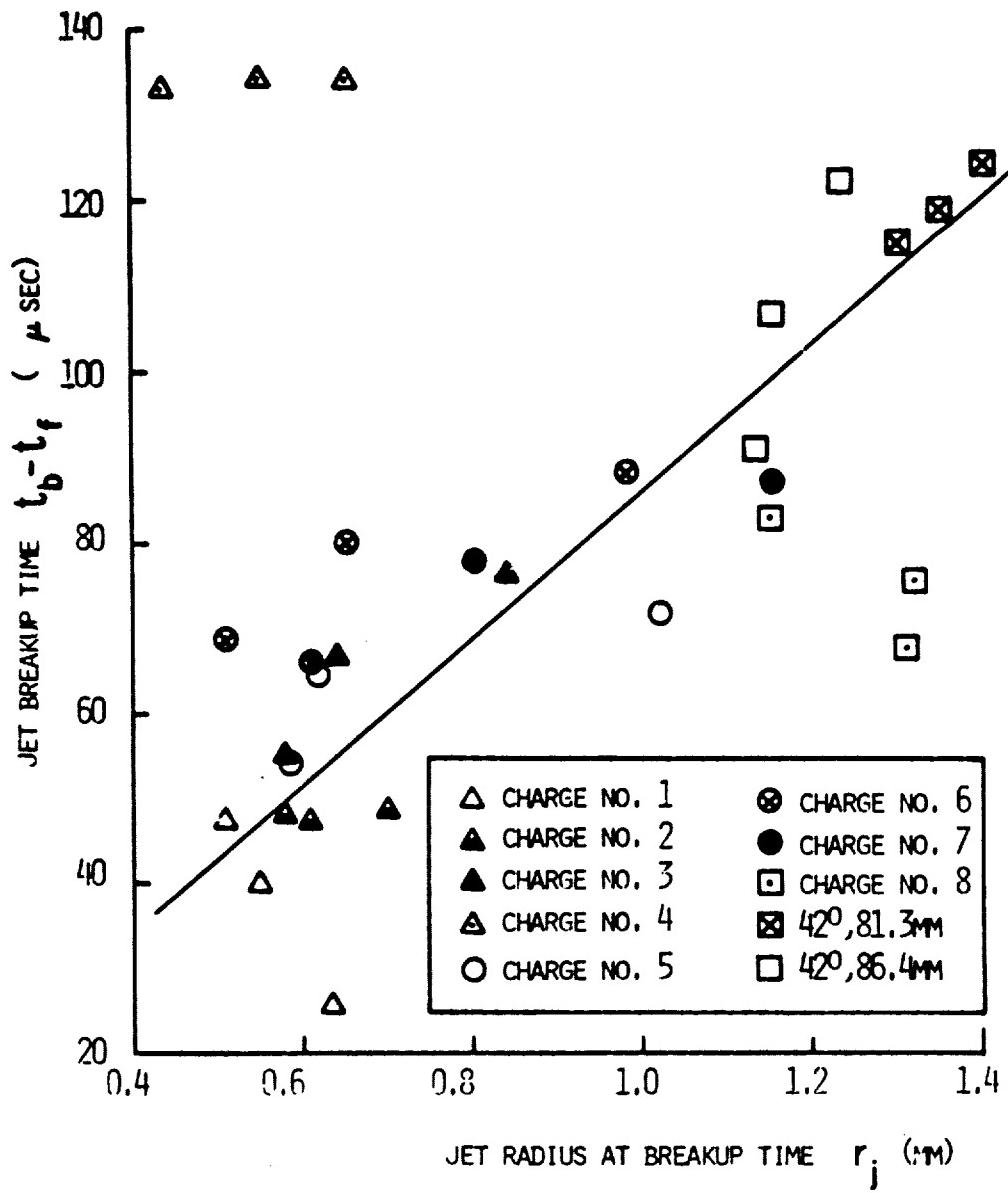


Figure 4. Breakup time vs. jet segment radius for various charges. Ten charges are included. Three data points selected from each charge.

### III. STABILITY OF SHAPED CHARGE JETS AS A CAUSE FOR BREAKUP

#### A. Background

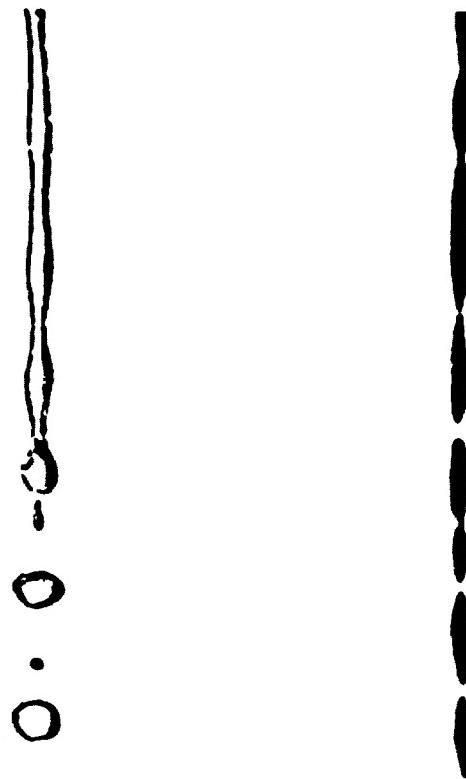
The concept of liquid jet stability in classical hydrodynamics has been studied by many authors (e.g. [11]-[14]). The idea of applying a stability approach to shaped charge jets was motivated by the remarkable resemblance of the breakup of shaped charge jets to that of liquid jets. This resemblance is shown in Fig. 5 where the breakup of a glycerine-water jet [15] is contrasted with a typical shaped charge jet. Further, we note that the average  $l/d$  ratio for all of the copper jet segments studied, 4.86 (see Table II), is very close to the value of the critical  $\lambda/2r_0$  ratio of 4.5 predicted by classical stability analyses of liquid jets, where  $\lambda$  is the wavelength of the surface disturbance, and  $r_0$  is the radius of the undisturbed jet. These facts suggest that the shaped charge breakup phenomenon may be caused by surface instability.

The first stability analysis of a liquid jet was published in 1879 by Lord Rayleigh [11]. He considered an inviscid fluid jet moving at a constant uniform axial velocity subjected to surface disturbances about the equilibrium position. He obtained the most unstable wavelength and the perturbation growth rate using energy considerations. His values of wavelength and growth rate have been verified by experiments, and his work is still considered the foundation for the study of jet stability.

Weber [12] extended Rayleigh's work to include viscous Newtonian fluids. The wavelength of the most unstable surface disturbance for a viscous fluid does not deviate too much from the ideal fluid case of  $(\lambda/2r_0) = 4.5$ . He also found that Newtonian viscosity tends to dampen the instability. Anno [16,17] gave a more general derivation of the analyses by Rayleigh and Weber.

Goldin, et al [15] studied the breakup of non-Newtonian viscous fluid jets. They used essentially the same approach as Levich [13] and obtained results on critical wavelength, growth rate, and breakup time for fluids possessing general viscoelastic stress-strain relations. In [15], it is shown that the Newtonian fluid is the most stable one among viscous fluids. Experimental evidence for different types of fluids seems to verify their results.

In our initial work, we have determined that three effects may cause jet breakup: surface tension, aerodynamic forces, and strength of the jet material. We have applied all the essential results of the classical analyses to the conditions of a typical shaped charge jet. We have also examined many experimental breakup records in the light of stability considerations. These results have ruled out the importance of the surface tension and aerodynamic effects in the stability of a shaped charge jet. This leaves the effect of jet strength. Since strength effects are not readily amenable to analytical treatment, we have turned to numerical approaches to study the



LIQUID JET  
75 % GLYCERINE-25 % WATER  
REFERENCE 15

SHAPED CHARGE JET  
COPPER  
81.3MM BRL STANDARD  
(RADIOGRAPH COURTESY R. JAMESON, BRL)

FIGURE 5. The resemblance between the breakup of  
a liquid jet and a shaped charge jet.

effects of jet strength.

In the next section of this report, we will first present results of a preliminary analytical study. Then more detailed results on the numerical study will be presented, including the study of various surface disturbances, time of disturbance initiation, strain rate, and inertia effects in jets with strength.

### B. Preliminary Analytical Stability Study of Shaped Charge Jets

The results and formulas developed in the classical analyses of liquid jet stability were applied to the case of a typical shaped charge copper jet. Analyses for non-stretching and stretching jets were used. The results of this study are summarized in Table IV and will be briefly discussed below.

#### 1. Non-stretching Jets

(a) Surface Tension. In our initial analysis, we have applied the classical formulas of Rayleigh [11] and Weber [12] to the conditions of a typical copper shaped charge jet. Rayleigh's work governs the case of an ideal fluid under the effect of surface tension and Weber's results are applicable to a viscous fluid under the effect of surface tension. The growth rate of disturbances on the surface of the jet as predicted from these formulas is quite small as compared to that observed in radiographs of shaped charge jets. In fact, according to these formulas the amplitude of the initial disturbance only grows 8% in 100  $\mu$ sec, whereas it is observed from experiments that the shaped charge jet used for this analysis breaks up at approximately 100  $\mu$ sec. The value of surface tension for copper used was 1.0 N/m.

(b) Aerodynamic Force. We have applied the formulas of Levich [13] to the problem of air passing over a shaped charge jet. A very large disturbance growth rate was predicted by this analysis. We feel, however, that the analysis is not too realistic for the present problem since Levich only considers linear incompressible aerodynamics and the present case is actually in the hypersonic regime. We would also like to indicate two experimental observations which demonstrate that aerodynamic effects are not important in the breakup of shaped charge jets. Vitali [18] has pointed out that superplastic jets do not breakup along their length in the typical manner of a copper jet, yet both jets are subject to the same aerodynamic force. Also, Frey [19] has studied photographs of copper jets in a vacuum, and found the typical surface disturbance growing within 100  $\mu$ sec, similar to those found in jets traveling through air.

#### 2. Stretching Jets

Mikami, et al [14] has developed an analytical approach to study the growth of disturbances on the surface of a stretching viscous thread surrounded by another viscous medium. We have modified this analysis to make it applicable to the case of a shaped charge jet. As shown in Table IV, appreciable growth rates and reasonable  $\lambda/2r$  ratios

Table IV  
Analytical Approaches to Shaped Charge Jet Stability

Approach Stretching	Medium	Surface Forces	Most Unstable $\lambda/2r$	Disturbance Growth Range	Other Comments
Rayleigh no	both ideal and viscous fluids	Surface tension	4.5	8% in 100 $\mu$ sec	
Levich no	viscous (Newtonian)	Aerodynamic force	4	1000% in 22 $\mu$ sec	used incompressible aerodynamics, not realistic for present case.
Present study yes	viscous (Newtonian)	None	8.9 after 64 $\mu$ sec (broad range)	100% in 64 $\mu$ sec	Inertia force neglected in governing equations
Present study yes	viscous (Newtonian)	Surface tension	5.2 after 16 $\mu$ sec (broad range)	100% in 16 $\mu$ sec	" "

were predicted by this analysis at times in the regime of typical breakup times: (Note that in the stretching jet case  $\lambda/2r$  changes with time thus making the comparison more complicated.) However, the approach of [14] has neglected inertia forces to make the governing equations analytically tractable. Because of the high strain rates present in the shaped charge problem inertia effects will be important. This importance of inertia effects will be verified by numerical calculations in the next sub-section. Thus, we feel that the results of this analytical method of [14] as applied to the shaped charge problem are not conclusive.

### C. Numerical Study of Shaped Charge Jet Stability

In the previous sub-section we have studied surface tension and aerodynamic effects on jet stability by relatively simple analytical techniques. Since effects such as material strength are, at present, not readily amenable to analytical treatment, we have used numerical techniques to study this and other effects. One advantage of numerical studies over analytical studies is that in the numerical treatment all of the pertinent effects may be included at the outset, whereas analytical treatments necessitate the use of certain simplifying assumptions.

#### 1. General Approach

The numerical study of jet stability was undertaken through the use of the two-dimensional code HEMP [20,21]. The HEMP code is a general purpose code which solves the conservation equations of two-dimensional elastic-plastic flow in plane coordinates or in axisymmetric coordinates. The solution is by the method of finite differences and uses the Lagrangian formulation. The code has the capability of handling many various boundary and initial conditions.

Karpp [22] first applied HEMP code calculations to the problem of a stretching elastic-plastic jet with the surface slightly disturbed. After calculating various wavelengths of the surface disturbance, he found a broad range of most unstable wavelengths with reasonable growth rates. We have applied the same basic method to study the breakup problem in more detail. The boundary and initial conditions of this method will now be briefly described.

A stretching shaped charge jet is modelled by a prismatic circular bar fixed at one end, with the other end moving at a constant velocity. A linear velocity distribution in the axial direction is imposed as the initial condition, and the surface of the bar is initially perturbed in the shape of a cosine function, as shown in Fig. 6. The perturbed surfaces are free from any tractions and the end surfaces are free of any shear stresses. Let the axial velocity be  $V(x, r, t)$ , the radial velocity be  $u(x, r, t)$ , the stress vector on the lateral surface be  $\tau(x, r_s, t)$ , and the shear stresses on the end surfaces be  $\tau_{rx}(0, r, t)$ ,  $\tau_{x\theta}(0, r, t)$ ,  $\tau_{rx}(L, r, t)$ ,  $\tau_{x\theta}(L, r, t)$ , then the boundary conditions are

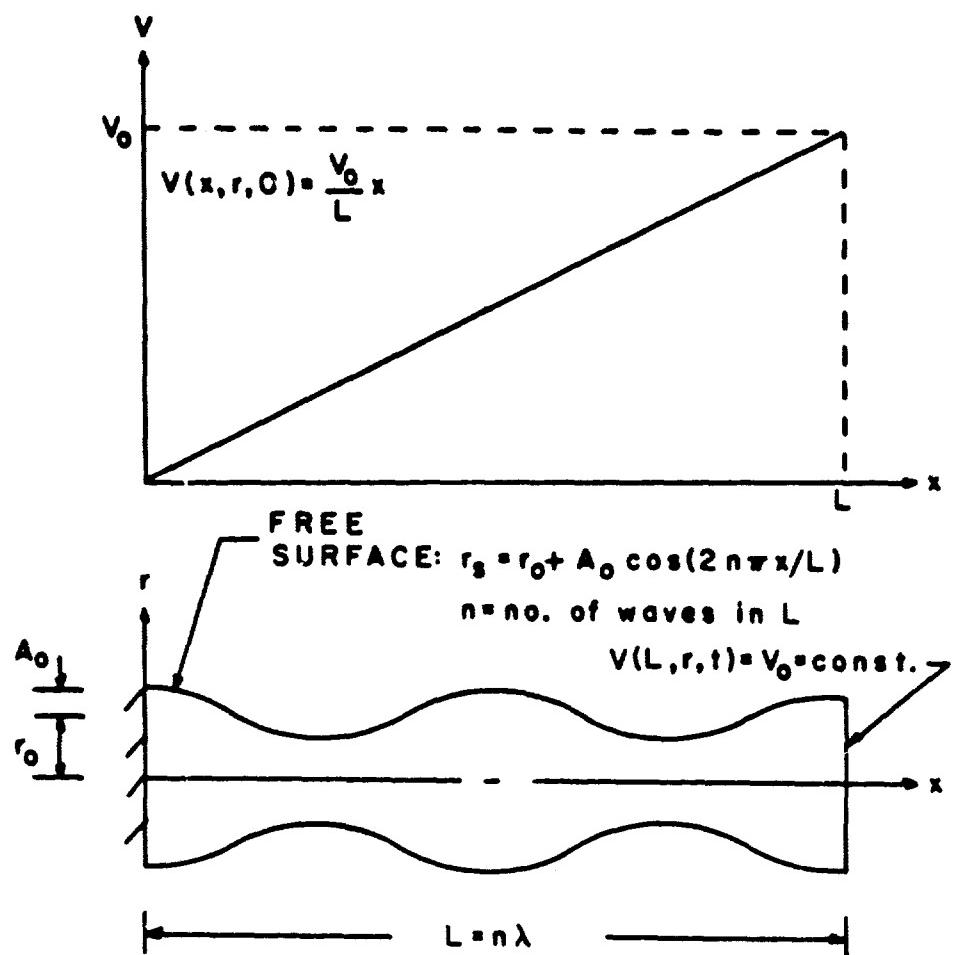


FIGURE 6. Initial and boundary conditions for the numerical jet stability computations.

$$\begin{aligned}
 v(0, r, t) &= 0 \\
 v(L, r, t) &= V_0 \\
 g(x, r_s, t) &= 0 \\
 \tau_{rx}(0, r, t) = \tau_{x\theta}(0, r, t) = \tau_{rx}(L, r, t) = \tau_{x\theta}(L, r, t) &= 0
 \end{aligned} \tag{1}$$

and the initial conditions are

$$\begin{aligned}
 v(x, r, 0) &= (V_0/L)x \\
 u(x, r, 0) &= 0
 \end{aligned} \tag{2}$$

The calculation may often be limited to only one cycle of the surface wave along the axial direction because of the symmetry of the problem.\*

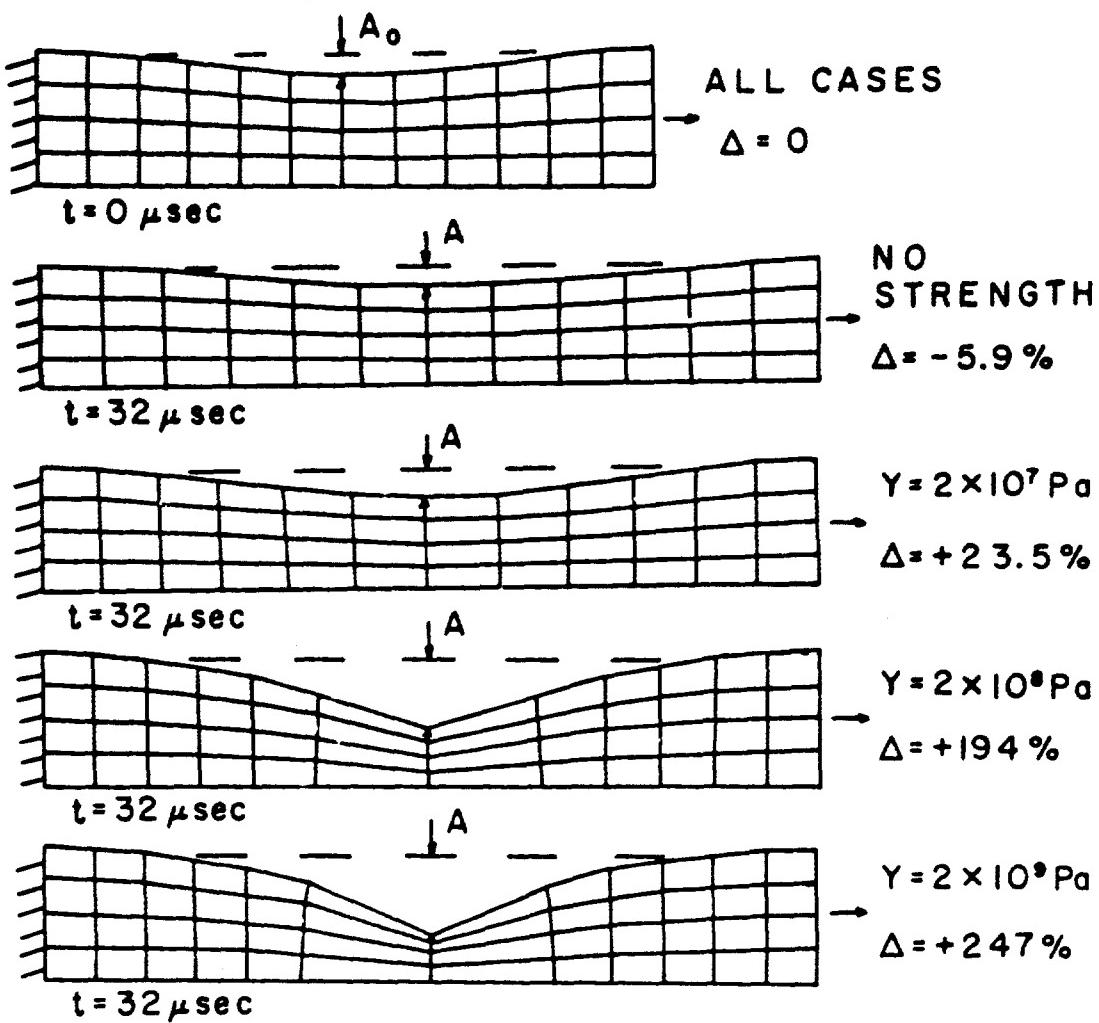
## 2. The Effect of Yield Strength

In the analytical studies discussed previously all of the jets were assumed to be fluid in nature and the driving forces for the instability were restricted to surface tensions, viscosity, and aerodynamic forces. Now we will study the effect of yield strength on the stability of an elastic-plastic jet.\*\*

To study this, we computed four jet segments having different yield strengths but being otherwise identical. In these calculations we selected a copper jet segment with one cycle surface disturbance having an initial length of 7.5mm and an initial mean radius of 1.5mm. The initial amplitude of the wave was taken as 10% of the initial radius. The velocity difference between the two ends of the segment was 0.0625 mm/usec. In a real jet this initial time corresponds typically to a time 50 usec after the segment was formed or approximately 100 usec after the detonation of a BRL 81.3mm charge. This initial configuration and calculation mesh is shown in Fig. 7. In all cases the copper equation of state as specified in HEMP was used. The value of density used was  $8.9 \times 10^3 \text{ kg/m}^3$  ( $8.9 \text{ g/cm}^3$ ) and the elastic shear modulus was taken as  $4.56 \times 10^{10} \text{ Pa}$  (456 kbar). The first of the four segments has no strength, i.e. purely fluid; the next three have yield strengths of  $2 \times 10^7 \text{ Pa}$  (.2 kbar),  $2 \times 10^8 \text{ Pa}$  (2 kbar), and  $2 \times 10^9 \text{ Pa}$  (20 kbar). The configuration after 32 usec for each of these four cases is also shown in Fig. 7. To compare results we have computed a quantity  $\Delta$ , the relative growth of amplitude, which is defined as the difference between the amplitude of the disturbance after stretching,  $A$ , and the initial amplitude,  $A_0$ , divided by the initial amplitude, i.e.  $(A - A_0)/A_0$ . This quantity is also given for each case in Fig. 7. We observe from these calculations that the disturbance grows faster for jets with larger values of yield strength.

\* We are studying a typical element in the middle of the jet. This element is being stretched by the force of the forward part of the jet on one side and the rear part of the jet on the other. The details of how the momentum and energy is transferred from one portion of the jet to another are currently being studied.

\*\* Note that Karpp and Simon [23] have recently studied the strength in shaped charge jets using the experimental results of rotating charges and also by using two-dimensional numerical calculations.



INITIAL LENGTH: 7.5MM

INITIAL MEAN RADIUS: 1.5MM

VELOCITY AT MOVING END:  $0.0625 \text{ MM}/\mu\text{SEC}$

$\Delta$  = RELATIVE GROWTH OF DISTURBANCE =  $(A - A_0)/A_0$   
 $Y$  = YIELD STRESS (ELASTIC-PERFECT PLASTIC)

FIGURE 7. Comparison of stretching jets with various yield strengths.

For static applications, we are used to the concept that, when comparing two materials, the one with higher strength will sustain larger stress, larger strain, and more stretching. Our present results indicate, however, that under dynamic conditions, the opposite case, which seems contrary to common sense, prevails. That is, under dynamic conditions of stretching, the material with higher yield stress is more unstable, will neck more, and break sooner.

### 3. The Effect of Disturbance Initiation Time

In this sub-section the effects of initiating the disturbance at various times in a realistic shaped charge jet are presented. Consider an element of a jet at several stages from the time when it is first formed until the time of its breakup as shown schematically in Fig. 8. This element of jet has an initial velocity difference of 0.13 mm/ $\mu$ sec between its two ends. The initial length and velocity gradient were selected such that, at the breakup time, the element will have a length equivalent to the average measured length of a typical jet segment from a 81.3mm BRL standard charge. We may therefore consider only one wavelength disturbance over this selected element. When this jet element is first formed one-dimensional calculations indicate its length would be approximately 1.1mm and its radius should be approximately 3mm. The times chosen to introduce the disturbance, labelled  $t_1$  through  $t_5$  in Fig. 8, correspond to times 0  $\mu$ sec, 7.92  $\mu$ sec, 17.62  $\mu$ sec, 25.69  $\mu$ sec, and 45.71  $\mu$ sec after the element was first formed, respectively. The overall dimensions of this element at these different times are summarized in Table V.

Table V

Dimensions of Jet Element Studied at Various Times After Its Formation

Run No.	Time after formation ( $\mu$ sec)	Element Length (mm)	Element radius (mm)	$\lambda/2r$	Amplitude of Imposed Disturbance (mm)	Strain Rate ( $\mu$ sec $^{-1}$ )
1	0	1.10	2.98	0.18	0.149	0.118
2	7.92	2.13	2.13	0.5	0.107	0.061
3	17.62	3.39	1.69	1.0	0.085	0.038
4	25.69	4.44	1.48	1.5	0.074	0.029
5	45.77	7.05	1.17	3.0	0.059	0.018

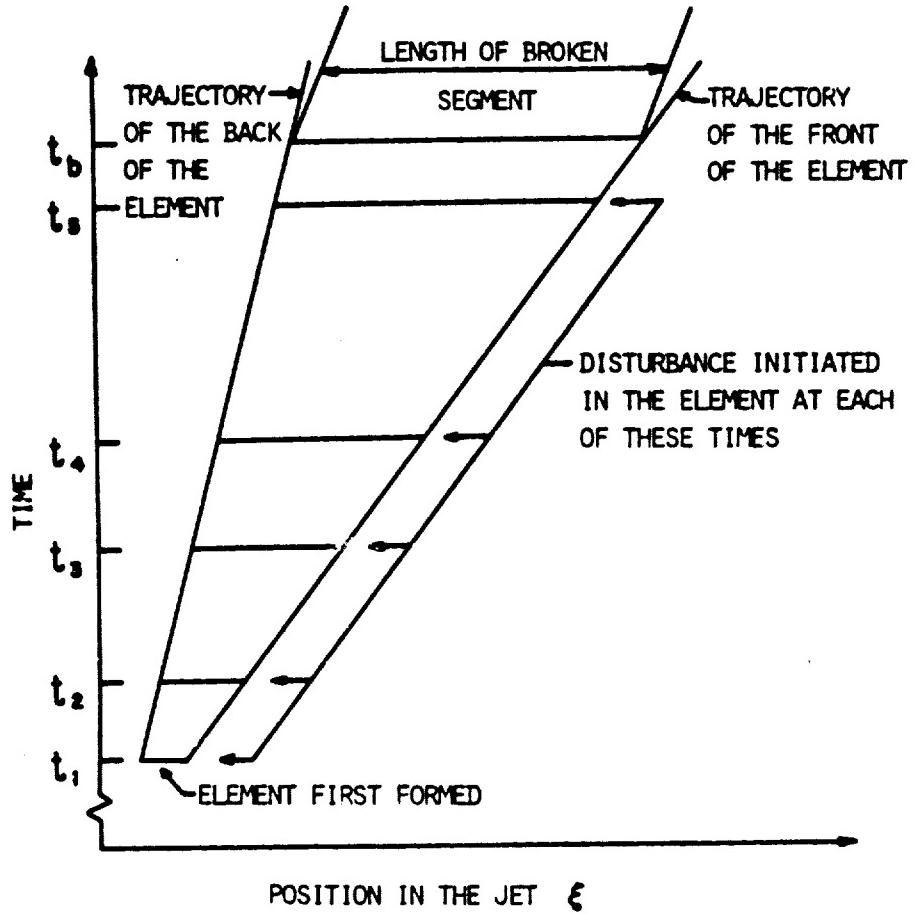


FIGURE 8. Schematic showing a position-time plot of a jet element which stretches to the typical breakup length. Disturbances are initiated separately at each of the times indicated for independent HEMP calculations of the element.

The HEMP calculations were performed using each of these times as a separate starting point. The disturbance was introduced independently at each of these times and each was treated as a separate problem. The equation of state and other constants for copper stated in the previous problem were again used. The yield stress was  $2 \times 10^9$  Pa (2 kbar). The amplitude of the imposed disturbance was taken at 5% of the radius in each instance and is also given in Table V.

The five HEMP calculations indicate that, during short times after the initiation of the disturbance, the amplitude of the surface disturbance in Run No. 4 grows the largest amount. This can be seen in Fig. 9, where the relative growth,  $\Delta$ , at a time 18  $\mu$ sec after the disturbance initiation for each case is plotted versus the initial strain rate. This gives an indication of how soon each disturbance begins to grow. As time proceeds, however, and we continue the calculations, the earlier configurations (Run Nos. 1-3) eventually reach a configuration similar to Run No. 4, and then the disturbance begins to grow quickly. This can be seen in Fig. 10 where the relative growth of Run Nos. 2, 3, and 4 are plotted versus time. Examining Run No. 2, we see that the disturbance is stable until a time of approximately 30-35  $\mu$ sec after formation, then the growth rate drastically increases. Run Nos. 3 and 4, in which the disturbance is initiated at times later than Run No. 2, also begin to grow more rapidly in the region 30-35  $\mu$ sec. Thus we see that, no matter how early we initiate the disturbance, when a critical time is reached, the disturbance will begin to grow and eventually the same final breakup configuration will be obtained.

#### 4. The Effect of Disturbance Wavelength

The effect of disturbance wavelength was studied by considering a jet of realistic radius and strain rate at a reasonably early time after formation and introducing surface disturbances of different wavelengths. A jet element having an initial radius of 2.13mm and an initial strain rate of  $0.061 \text{ usec}^{-1}$  was used. The equation of state and material constants for copper stated in the previous problem were again used. Four separate surface disturbances having initial wavelengths of 1.065mm, 2.13mm, 4.26mm, and 8.52mm were introduced and HEMP calculations made for each case. Note that we have chosen this problem such that the case  $\lambda = 2.13\text{mm}$  will eventually grow to the observed segment length after the experimentally determined breakup time for a typical shaped charge jet. Let us denote this "correct" initial wavelength as  $\lambda_0 = 2.13\text{mm}$ . We can then denote the other cases as  $\lambda = \lambda_0/2$ ,  $\lambda = 2\lambda_0$  and  $\lambda = 4\lambda_0$ . The relative growth, as computed using the HEMP code for each of these cases, is plotted vs. time in Fig. 11. From this plot we see that the disturbances having initial wavelengths of  $\lambda = \lambda_0/2$  and  $\lambda = 4\lambda_0$  grow very slowly. The wavelength  $\lambda = \lambda_0$ , which will grow into the proper segment size, grows very quickly but not quite as fast as the case  $\lambda = 2\lambda_0$ .

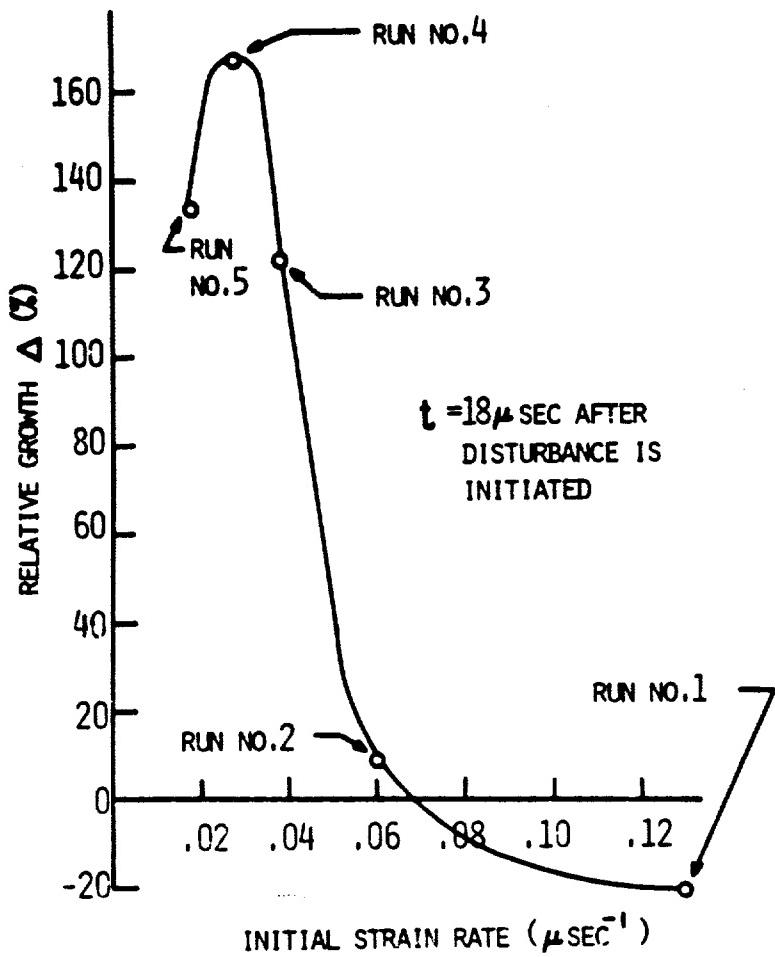


FIGURE 9. Relative growth vs. initial strain rate for five successive element configurations at  $18 \mu\text{sec}$  after disturbance initiation in each configuration.

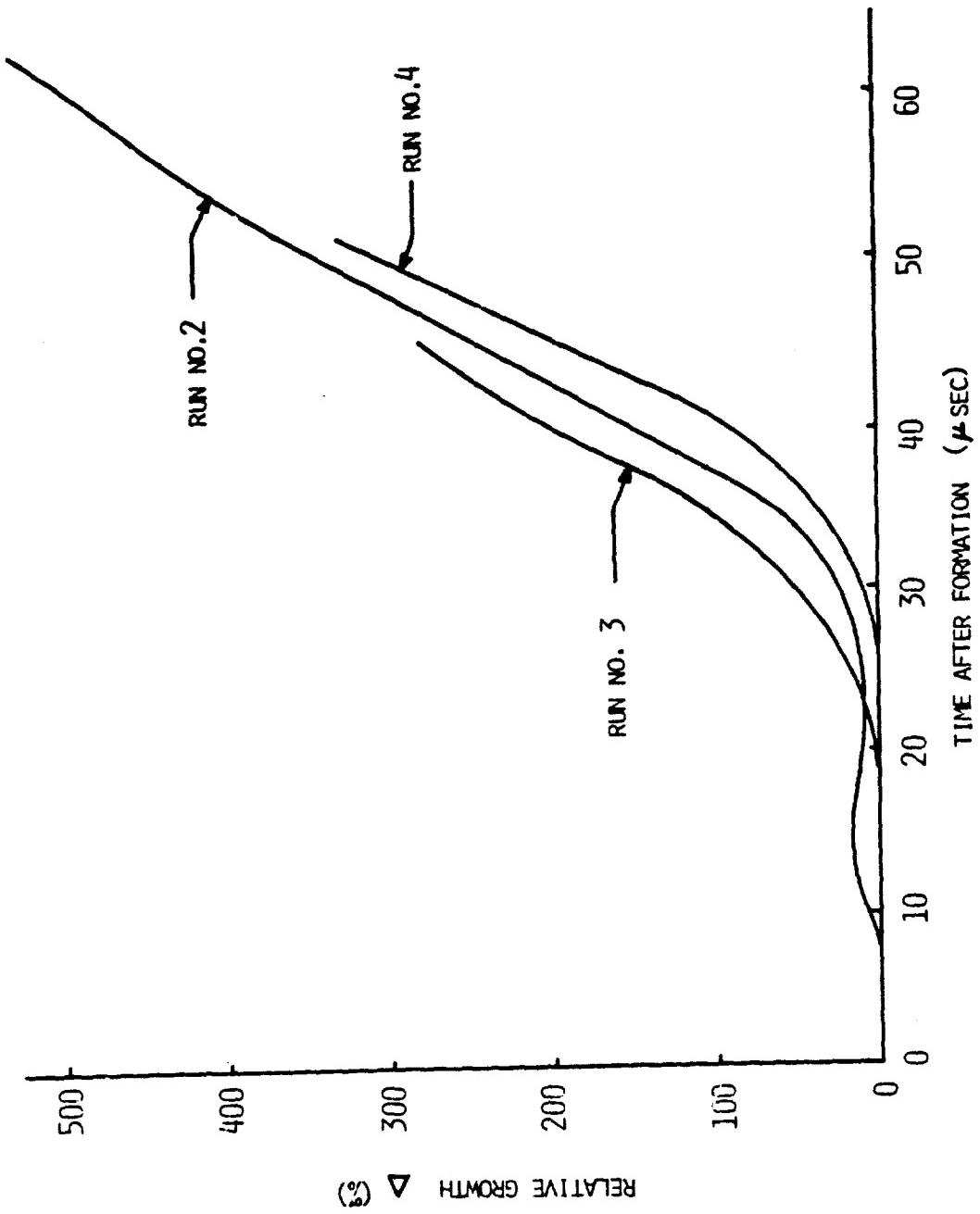


FIGURE 10. Relative growth vs. time for three different disturbance initiation times in a typical jet element.

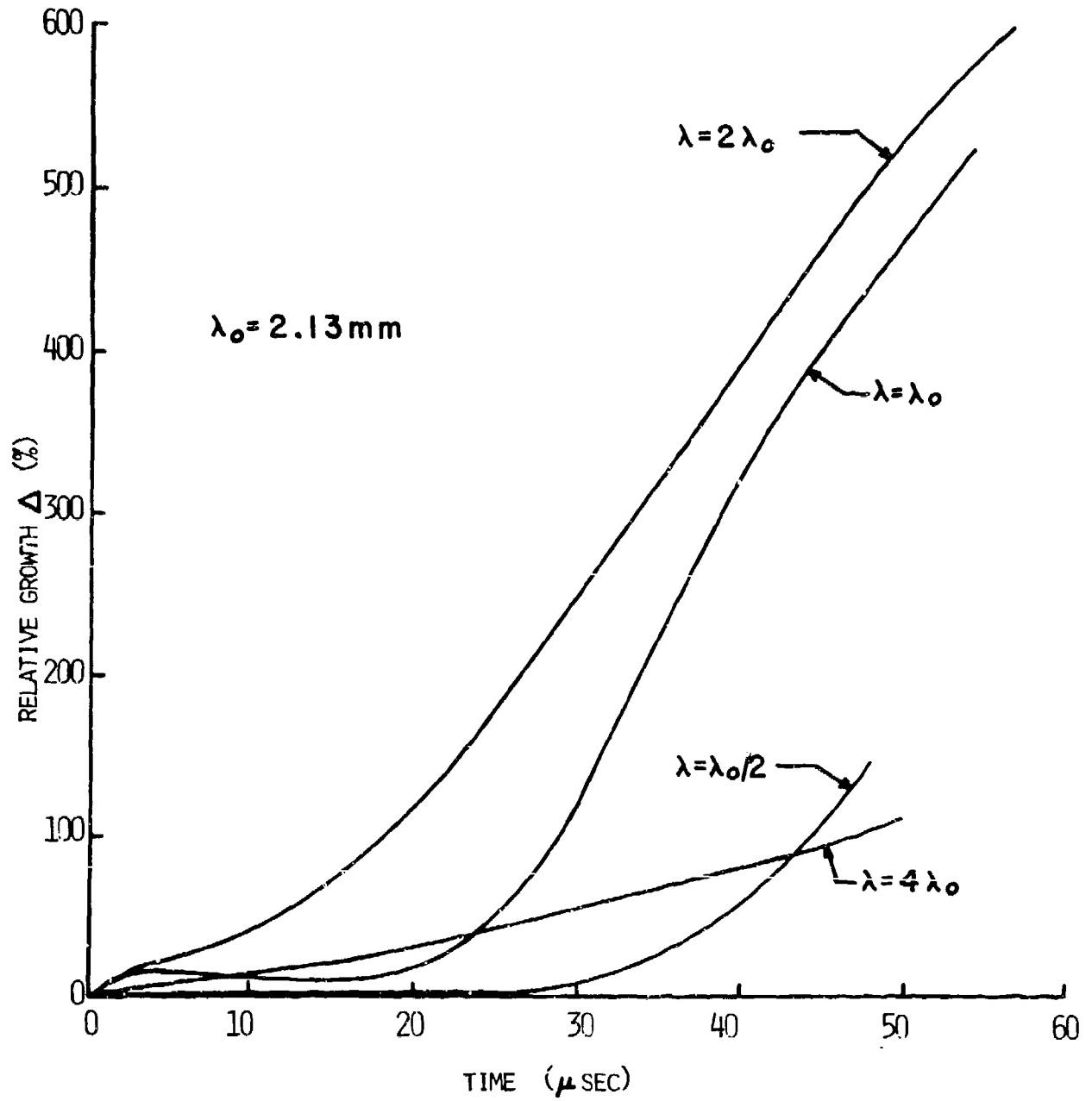


FIGURE 11. Relative growth vs. time for surface disturbances of four different wavelengths. In all cases, the jets initially have the same radius and strain rate.

## 5. Irregular Surface Disturbance

To examine these wavelength effects further, we have numerically studied jets having an irregular surface disturbance. In previous cases, we have considered jets having a surface of a single sinusoidal curve. Next, we have combined the four wavelengths of the previous study to obtain an irregular surface disturbance which is described by the following function:

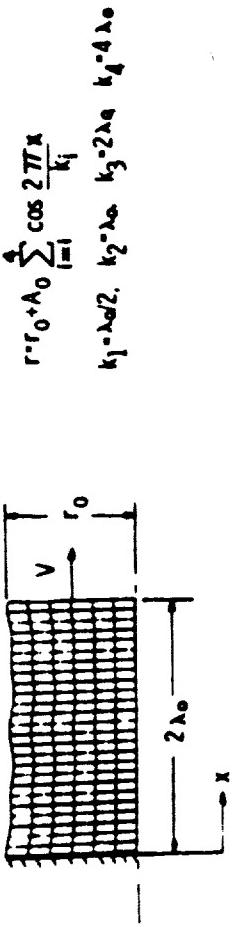
$$r_s = r_0 + A_0 \sum_{i=1}^4 \cos \frac{2\pi x}{k_i}$$

where  $k_1 = \lambda_0/2$ ,  $k_2 = \lambda_0$ ,  $k_3 = 2\lambda_0$ ,  $k_4 = 4\lambda_0$ . We have taken numerical values to be  $r_0 = 2.13\text{mm}$ ,  $\lambda_0 = 2.13\text{mm}$ ,  $A_0 = 0.026\text{mm}$ , and the initial strain rate equal to  $0.061\text{ usec}^{-1}$ . We again used the material constants for copper described previously. The initial configuration which has a length of  $2\lambda_0$  is shown in Fig. 12, together with the configuration after 52 usec. We observe that the jet appears to neck in two places. This indicates that  $\lambda_0$  is the dominant or fastest growing wavelength, which is in agreement with the experimentally obtained segment length. To demonstrate this more quantitatively, we have fit a Fourier series to the outer surface of the configuration after 52 usec shown in Fig. 12 and have examined the coefficients of the terms of each wavelength. Denoting the length after 52 usec as  $2\lambda_1$ , we observe that the largest of all the Fourier coefficients is that of the term containing the length  $\lambda = \lambda_1$ . A comparison of the coefficients of the four wavelengths of interest are also shown in Fig. 12. Thus, this result indicates that the component with an initial wavelength of  $\lambda = \lambda_0$ , which stretches into  $\lambda = \lambda_1$  after 52 usec is the most critical one.

In the case above, the initial disturbance consists of four waves of different wavelength, which are all "in phase". We performed yet another irregular surface disturbance calculation. In this calculation, a "random" disturbance was used which was comprised of five waves of different wavelength and phase angle, so that the waves would not be "in phase" at the ends. Thus, this new disturbance represents more closely a random one. The function used for the surface was

$$r_s = r_0 + A_0 \sum_{i=1}^5 \cos \left( \frac{2\pi x}{k_i} - \phi_i \right)$$

where  $k_1 = \lambda_0/2$ ,  $k_2 = \lambda_0/4$ ,  $k_3 = \lambda_0$ ,  $k_4 = 3\lambda_0/2$ ,  $k_5 = 2\lambda_0$ , and  $\phi_1 = 47^\circ$ ,  $\phi_2 = 36^\circ$ ,  $\phi_3 = 48^\circ$ ,  $\phi_4 = 54^\circ$ ,  $\phi_5 = 33^\circ$ . Numerical values were taken as  $r_0 = 2.13$ ,  $\lambda_0 = 2.13\text{mm}$ ,  $A_0 = 0.053\text{mm}$ , and the initial strain rate equal to  $0.061\text{ usec}^{-1}$ . The initial configuration and the configuration after 40 usec of stretching as calculated by the HEMP code are shown in Fig. 13. We see the jet necking in two places which again indicates that the growth of the  $\lambda = \lambda_0$  wave predominates and that the proper jet segment length will be attained at breakup.



a. INITIAL CONFIGURATION

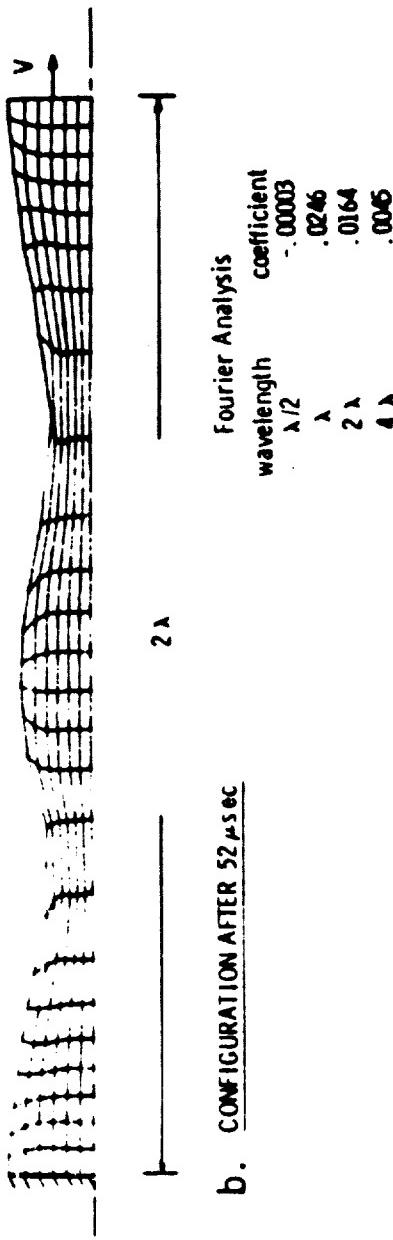
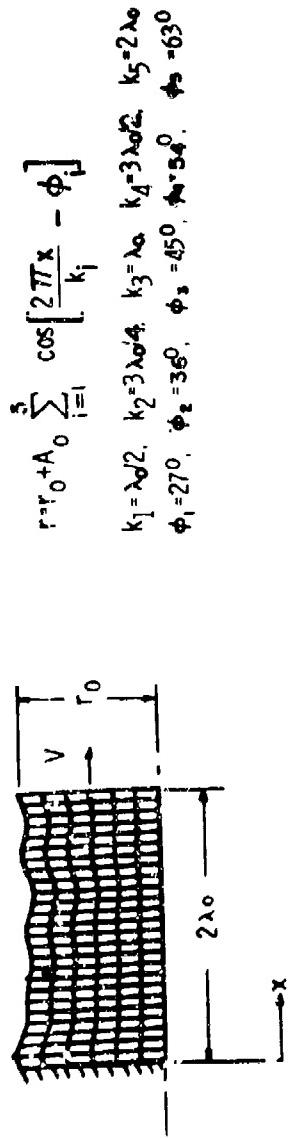


FIGURE 12. Results of HEMP calculations of a stretching jet with an irregular surface disturbance.



a. INITIAL CONFIGURATION

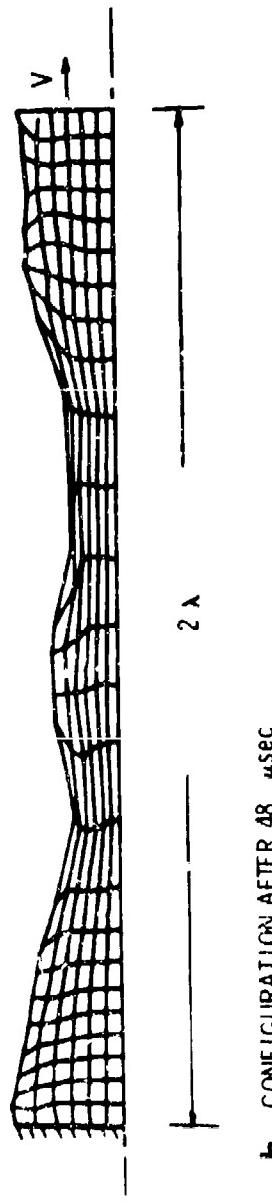


FIGURE 13. Results of HEMP calculations of a stretching jet with "random" surface disturbances.

### 6. The Effect of Inertia

To study the importance of inertia effects on the growth of surface disturbances in stretching shaped charge jets, we have made HEMP code calculations of three jets. Each jet was identical in all respects except for the density of the material used in the calculations. The configuration used was the standard single wave surface disturbance depicted in Fig. 6 with  $r_0 = 2.13\text{mm}$  and wavelength equal to  $2.13\text{mm}$ . The initial amplitude used was  $A_0 = 0.107\text{mm}$  and the initial strain rate equal to  $.061 \text{ usec}^{-1}$ . The equation of state and material constants described previously for copper were used except now three different values of density were used  $\rho_0 = 1 \times 10^3 \text{ kg/m}^3$ ,  $\rho_0 = 8.9 \times 10^3 \text{ kg/m}^3$ , and  $\rho_0 = 16.5 \times 10^3 \text{ kg/m}^3$ . The relative growth vs. time for each case is plotted in Fig. 14. We observe that increased density, i.e. increased inertia force, has a retarding effect on disturbance growth.

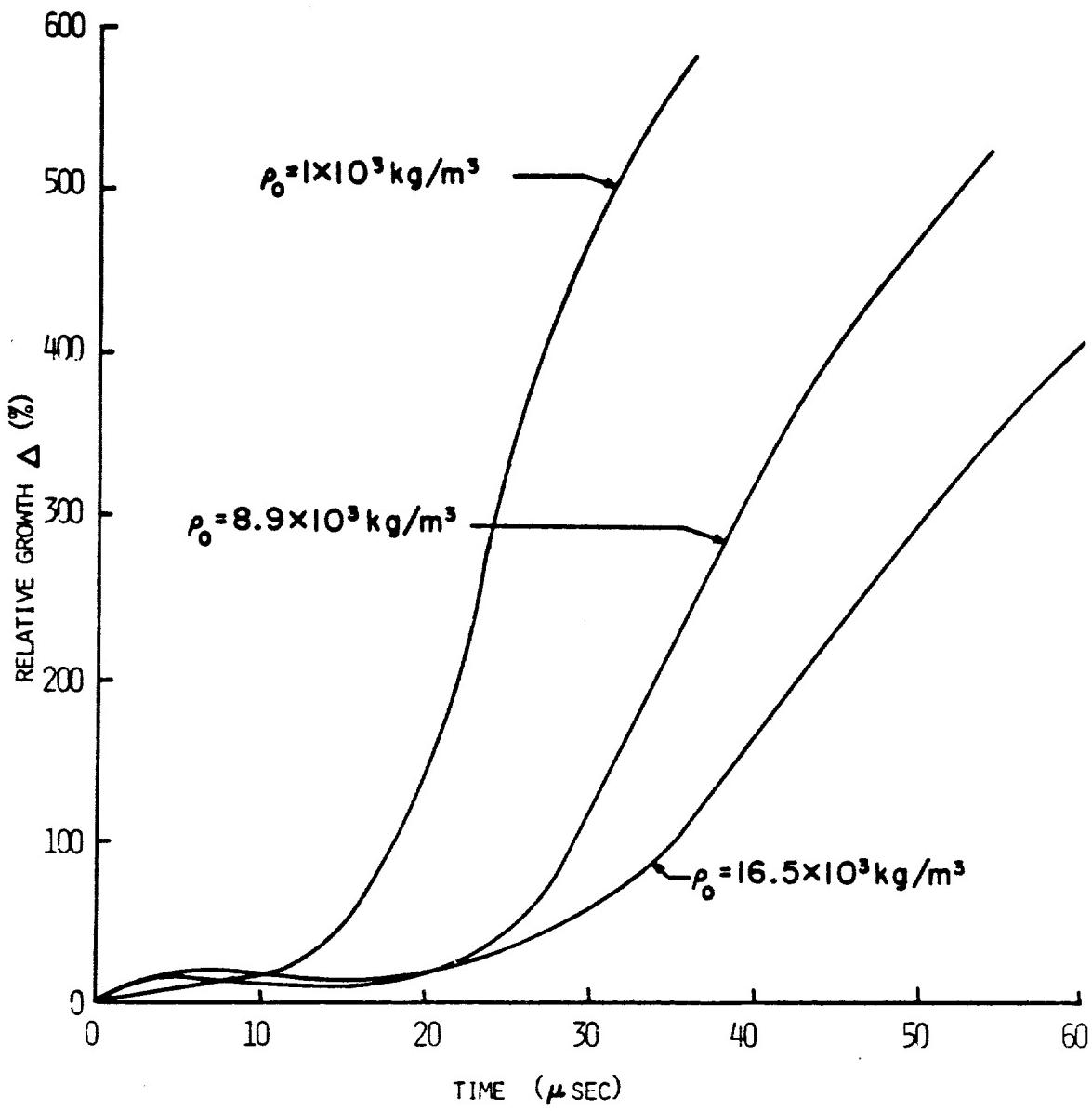


FIGURE 14. Relative growth vs. time for the stretching jets of different densities as predicted by HEMP.

#### IV. CONCLUSIONS

The major results and conclusions of the present research may be summarized as follows:

##### A. Measurement of Jet Radiographs

1. Data from jet radiographs, including jet velocity, breakup time, and segment size, for jets from eleven charges were compiled and plotted for easy reference.
2. These measured jet velocity and jet radius data agree closely with those calculated from a one-dimensional shaped charge model.
3. Analysis of this data together with using one-dimensional calculations resulted in a semi-empirical breakup time vs. jet radius curve for copper jets. This curve can be used to estimate an approximate breakup time for new charge designs.

##### B. Stability of Shaped Charge Jets

1. Simple stability analyses and experimental results indicate that surface tension and aerodynamic forces are not important in the breakup of shaped charge jets.
2. Numerical HEMP code calculations of stretching elastic-plastic jets subjected to surface disturbances were conducted. The effects of material yield strength, time of disturbance initiation, wavelength of the disturbance, irregular surface disturbances and jet density were examined. The following results were found:
  - a. Jets with higher yield strengths break sooner, all else being equal.
  - b. Jets with lower densities will break sooner, all else being equal.
  - c. For the shaped charge jet calculated, there is a critical time for the growth of the disturbance amplitude. Disturbances introduced early do not grow appreciably before this time, but grow rapidly after this critical time. Disturbances introduced after this time also grow rapidly.
  - d. A critical wavelength (or a range of wavelengths) exists; disturbances having this wavelength grow faster than all others. The length of the broken jet segment caused by this critical wave is in the range of measured jet segment lengths.
  - e. When irregular, or random, surface disturbances are introduced, the growth is again dominated by the disturbance component with the critical wavelength. The jet surface grows into a shape similar to that obtained if

only the wave with the critical length were introduced.

3. Materials with high density and low yield strength are promising liner materials which will likely retard the breakup of the resulting jet.

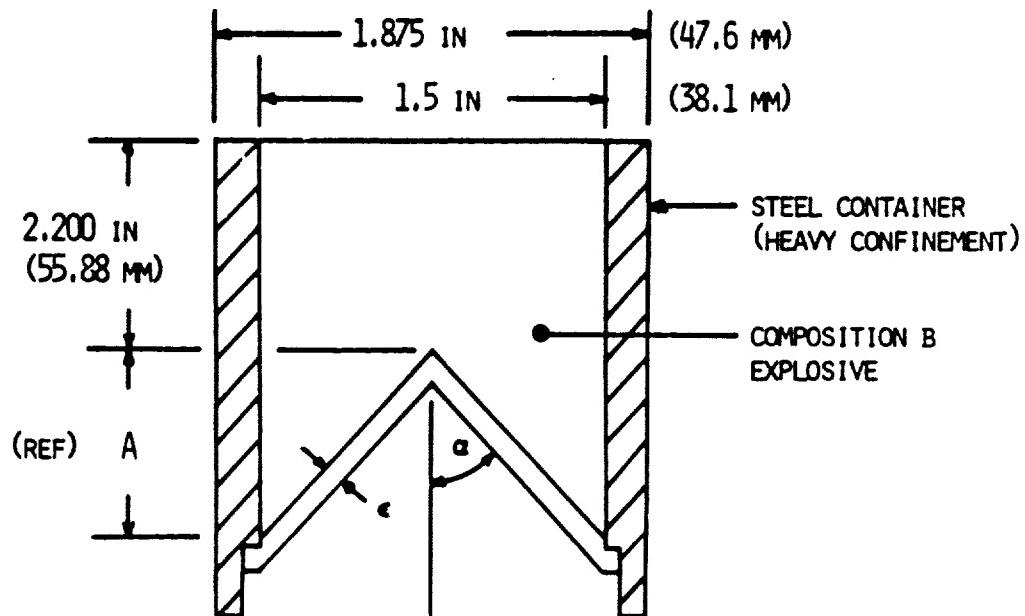
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Appendix A

This appendix contains the specifications of the eleven charges  
studied in this report.



CHARGE NO.	LINER MAT'L	$\alpha$	$\epsilon$ IN (MM)	A IN (MM)
1	Cu	10°	0.046 1.168	4.253 108.0
2	Cu	20°	0.046 1.168	2.061 52.35
3	Cu	30°	0.046 1.168	1.299 33.00
4	Cu	45°	0.046 1.168	0.750 19.05
9	AL	20°	0.064 1.626	2.061 52.35
10	AL	30°	0.064 1.626	1.299 33.00
11	AL	45°	0.064 1.626	0.750 19.05

FIGURE A1. Geometry of the 38.1 mm Copper and Aluminum lined charges with various cone angles.  
(Charge Nos. 1-4, 9-11)  
(from Ref. 3)

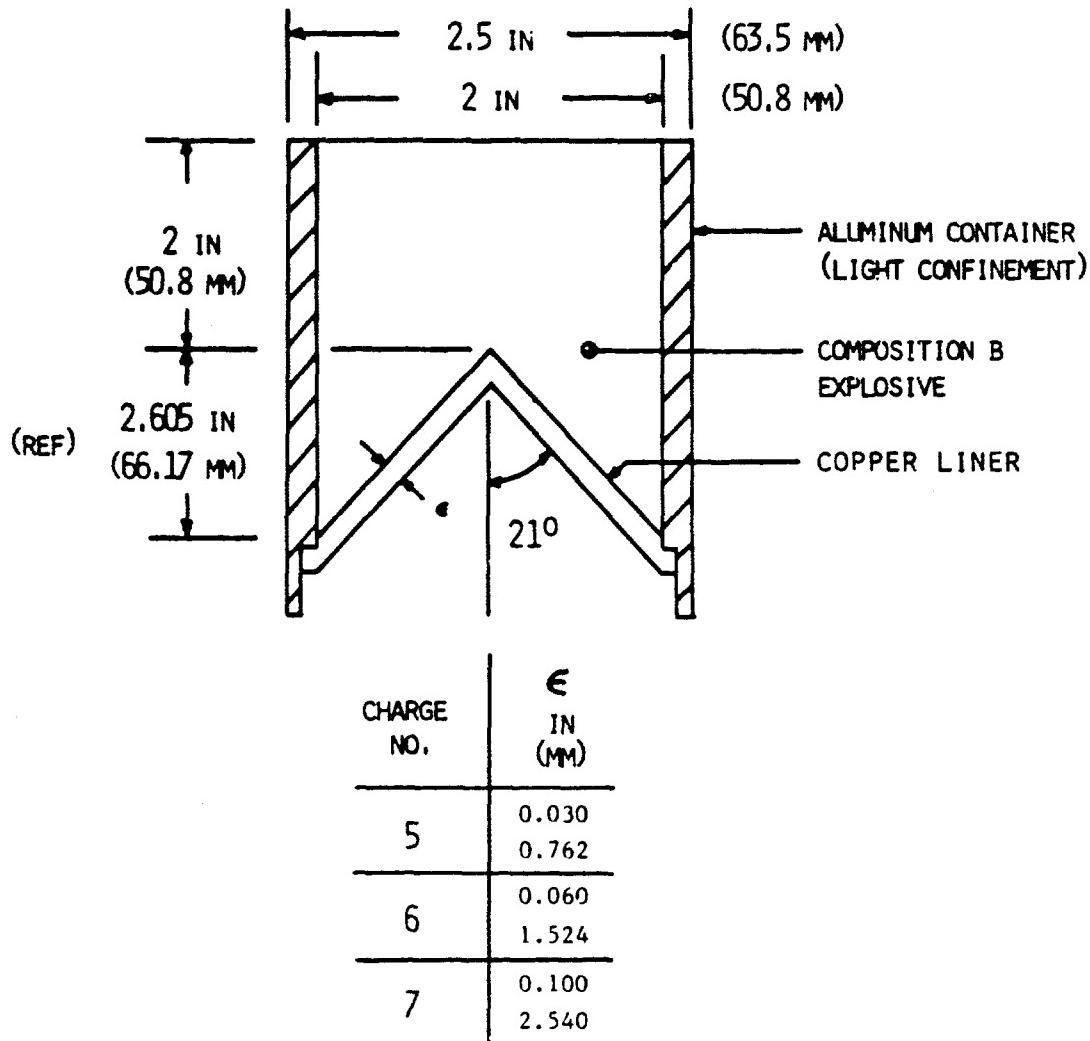


FIGURE A2. Geometry of the 50.8 mm, 42° Copper lined charges with different wall thicknesses.  
(Charge Nos. 5-7)  
(Courtesy of R. Jameson)

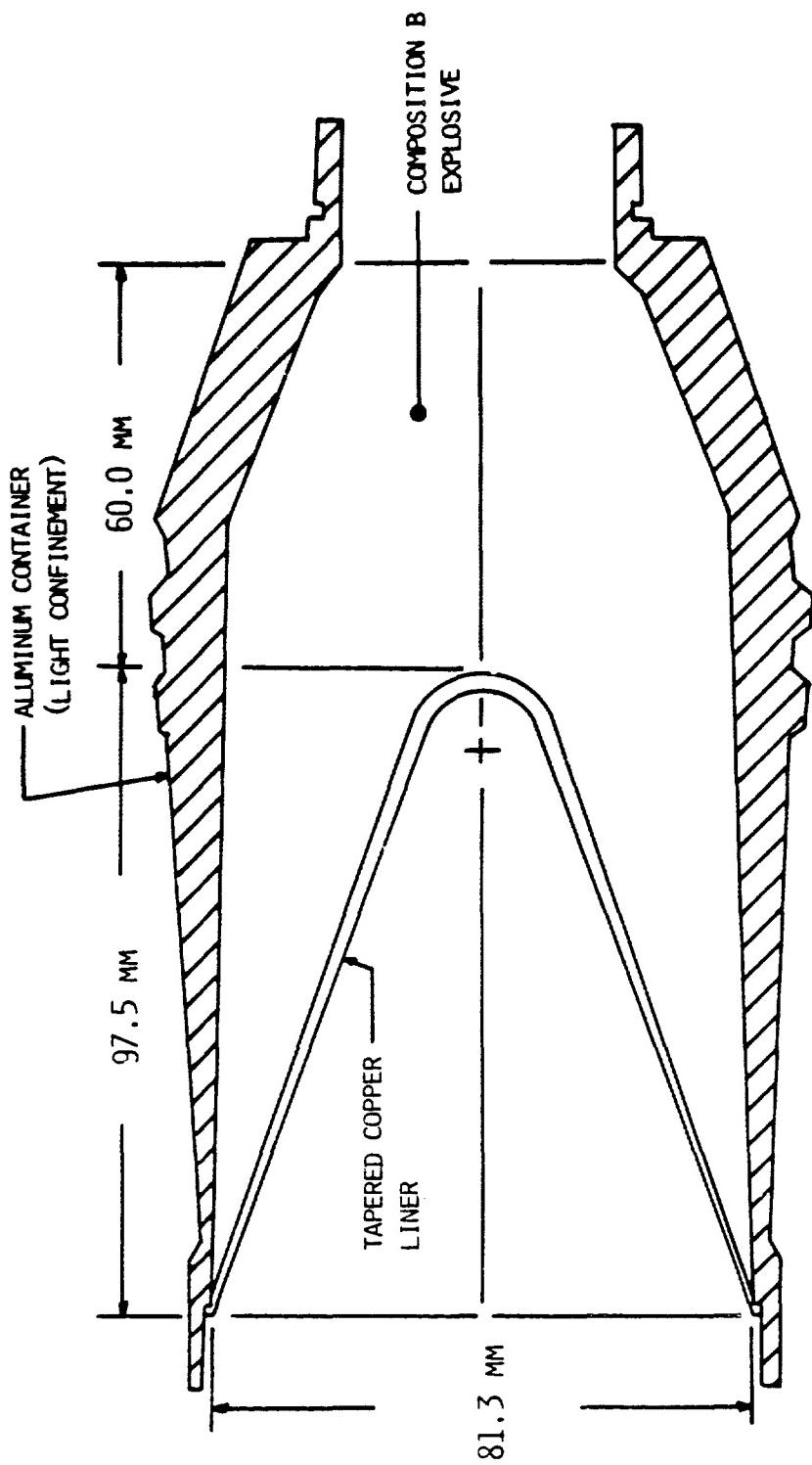


FIGURE A3. Overall dimensions of the 81.3 mm, 42° tapered  
wall charge.  
(Charge No. 8)  
(Ref. 24, except liner)

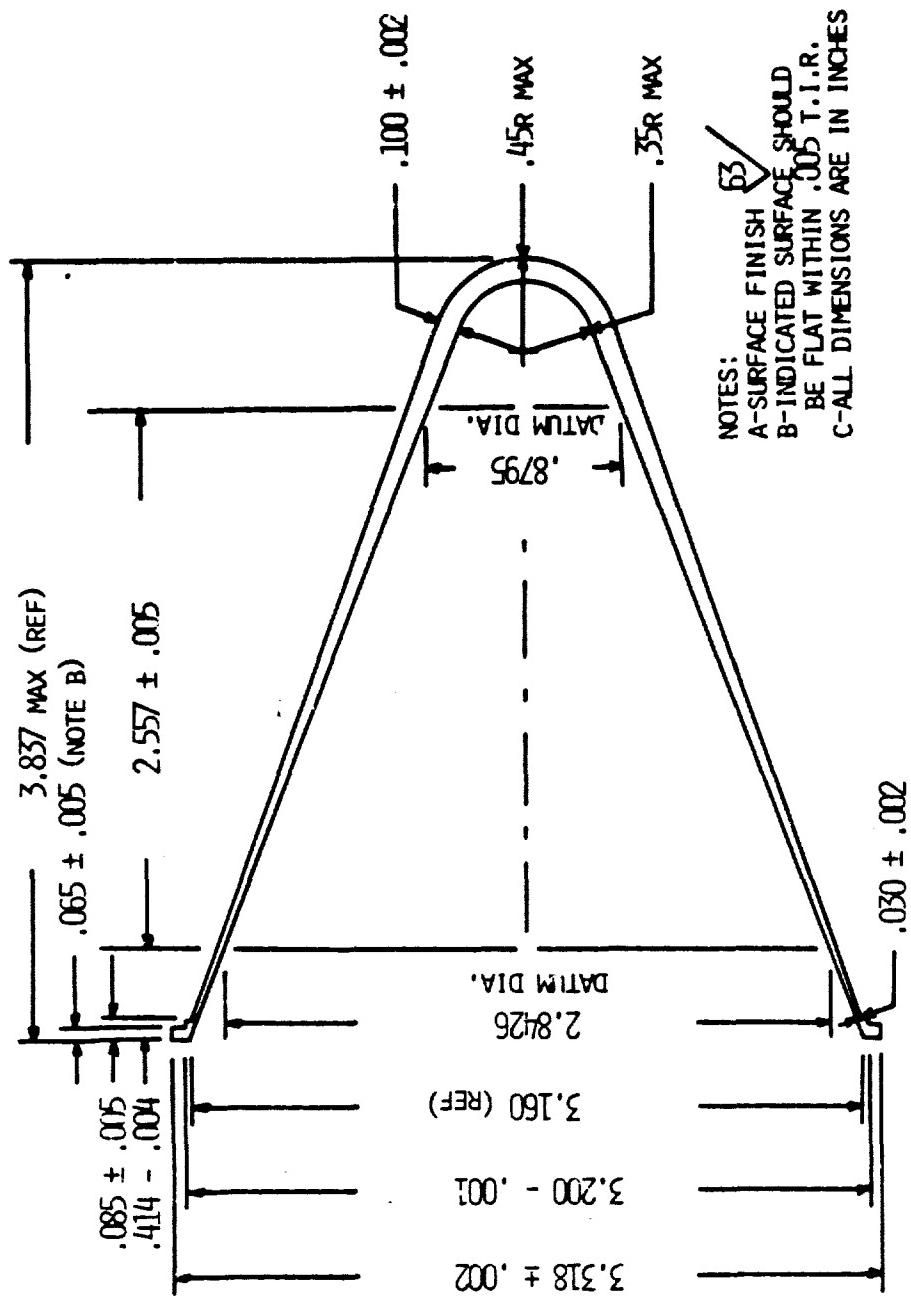


FIGURE A4. Details of the 81.3 mm,  $42^\circ$  tapered liner.  
 (Charge No. 8) (Liner was made at BRL.)  
 (Courtesy of R. Jameson)

Appendix B

This appendix contains a graphical display of jet velocity, jet breakup time, and jet radius data computed from the jet radiographs of the eleven charges studied in this report.

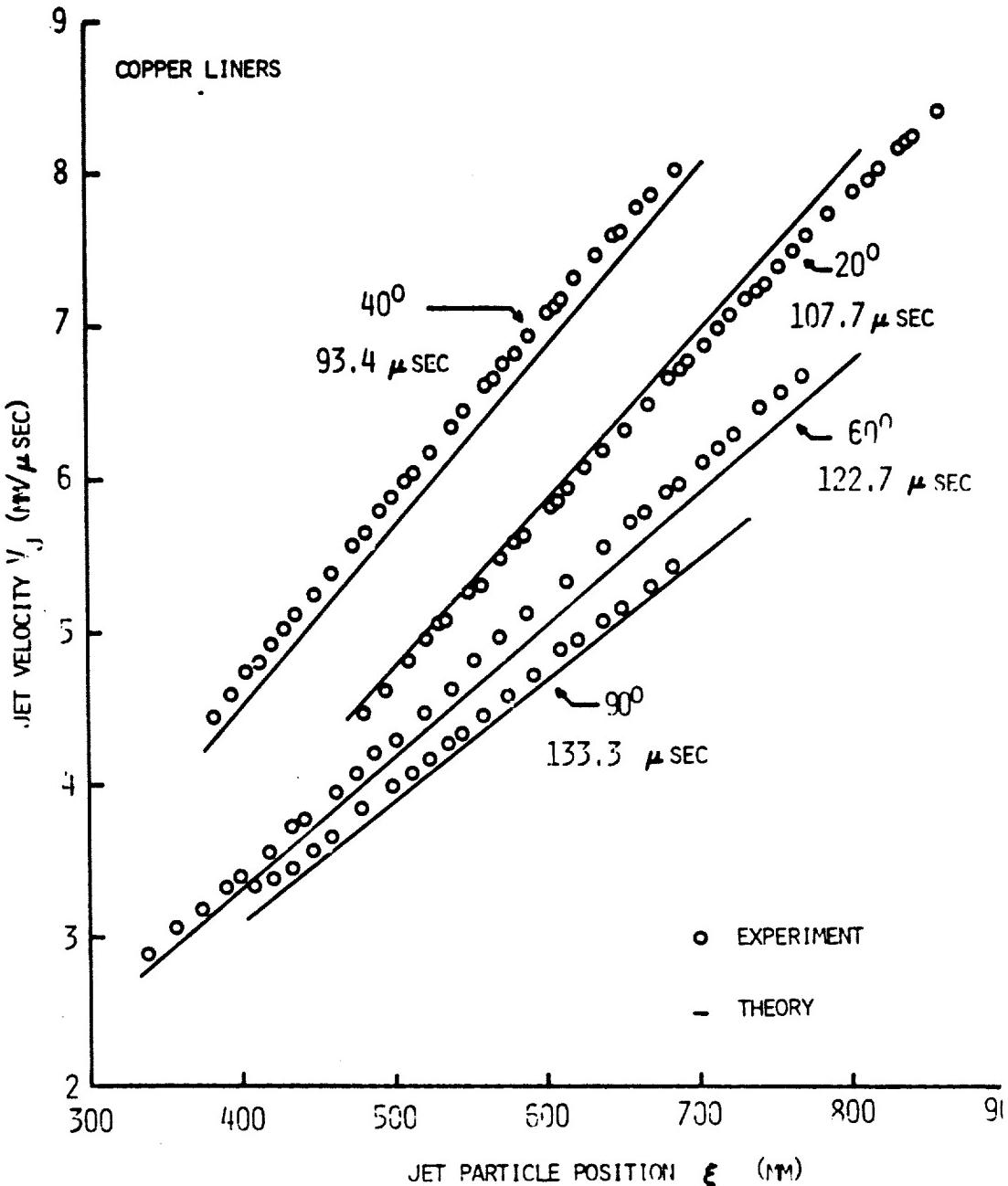


FIGURE B1. Theoretical and experimental jet velocity vs. jet particle position for the series of 38.1mm, 1.168mm wall, copper lined charges with various cone angles at various times after the arrival of the detonation wave at the cone apex. (charge nos. 1-4).

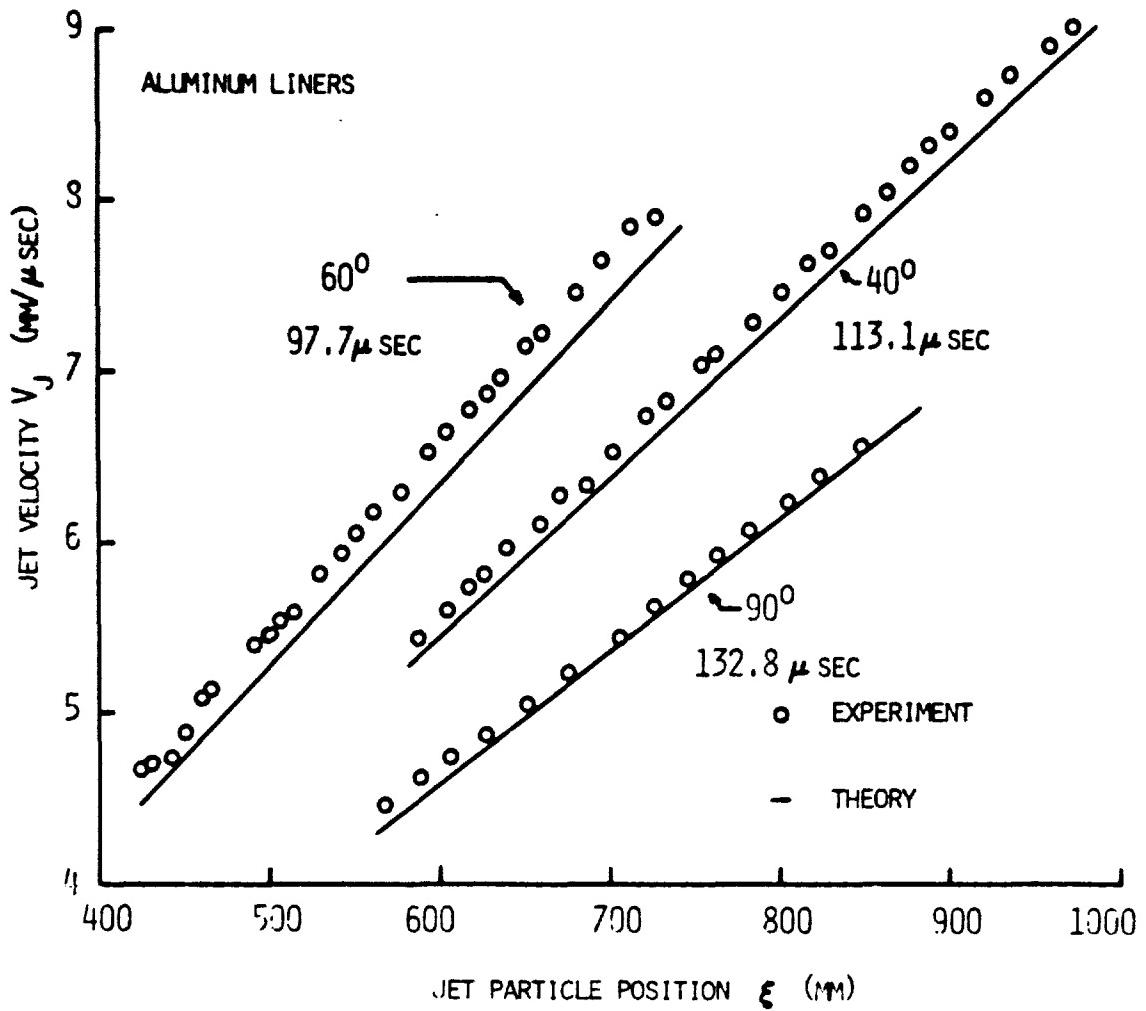


FIGURE B2. Theoretical and experimental jet velocity vs. jet particle position for the series of 38.1mm, 1.626mm wall, aluminum lined charges with various cone angles, at various times after the arrival of the detonation wave at the cone apex. (Charge Nos. 9-11)

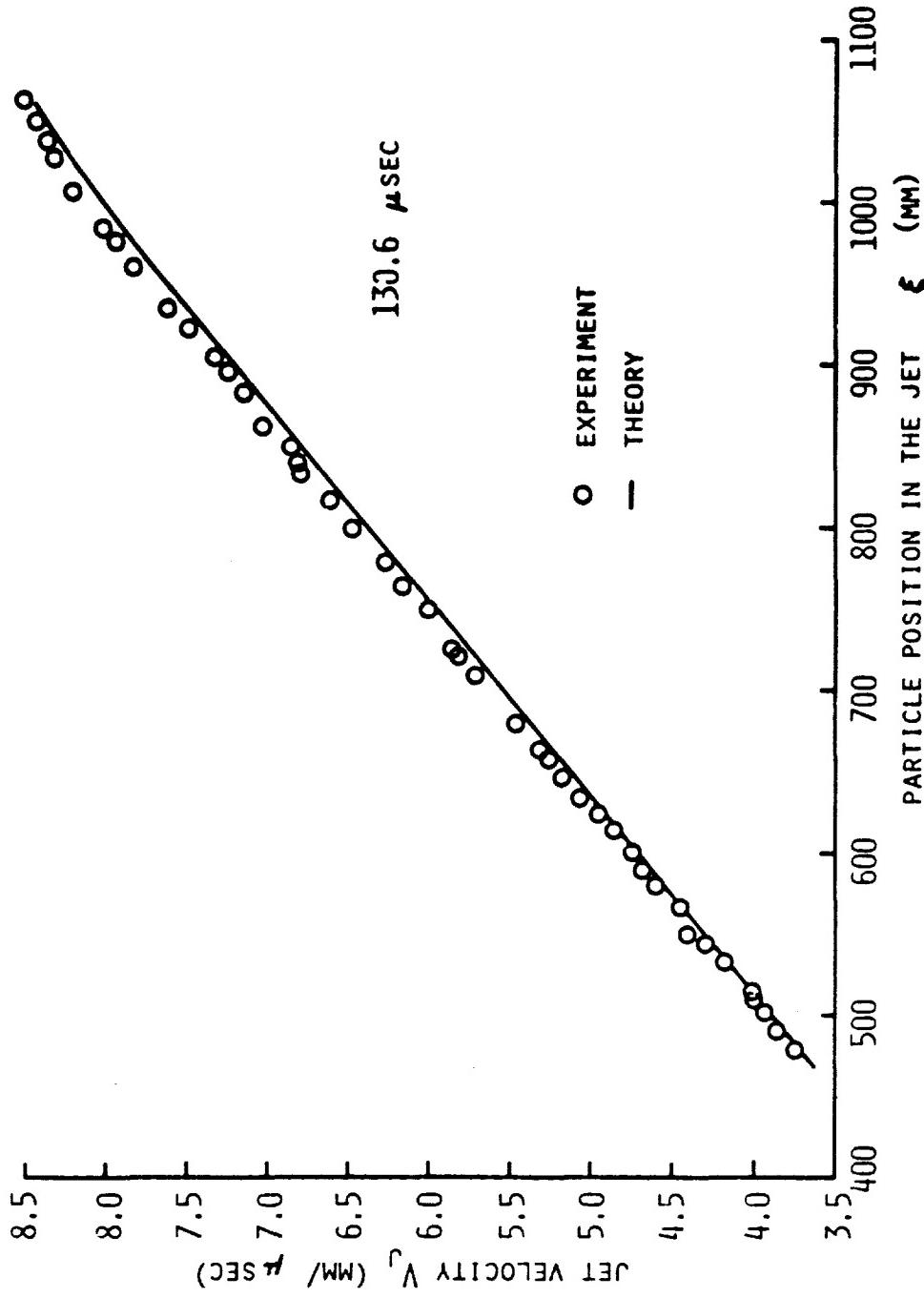


FIGURE B3. Theoretical and experimental jet velocity vs. jet particle position for the 50.8mm, 42°, 0.762mm wall copper lined charge at 130.6 usec after detonation wave arrival at cone apex. (charge No. 5)

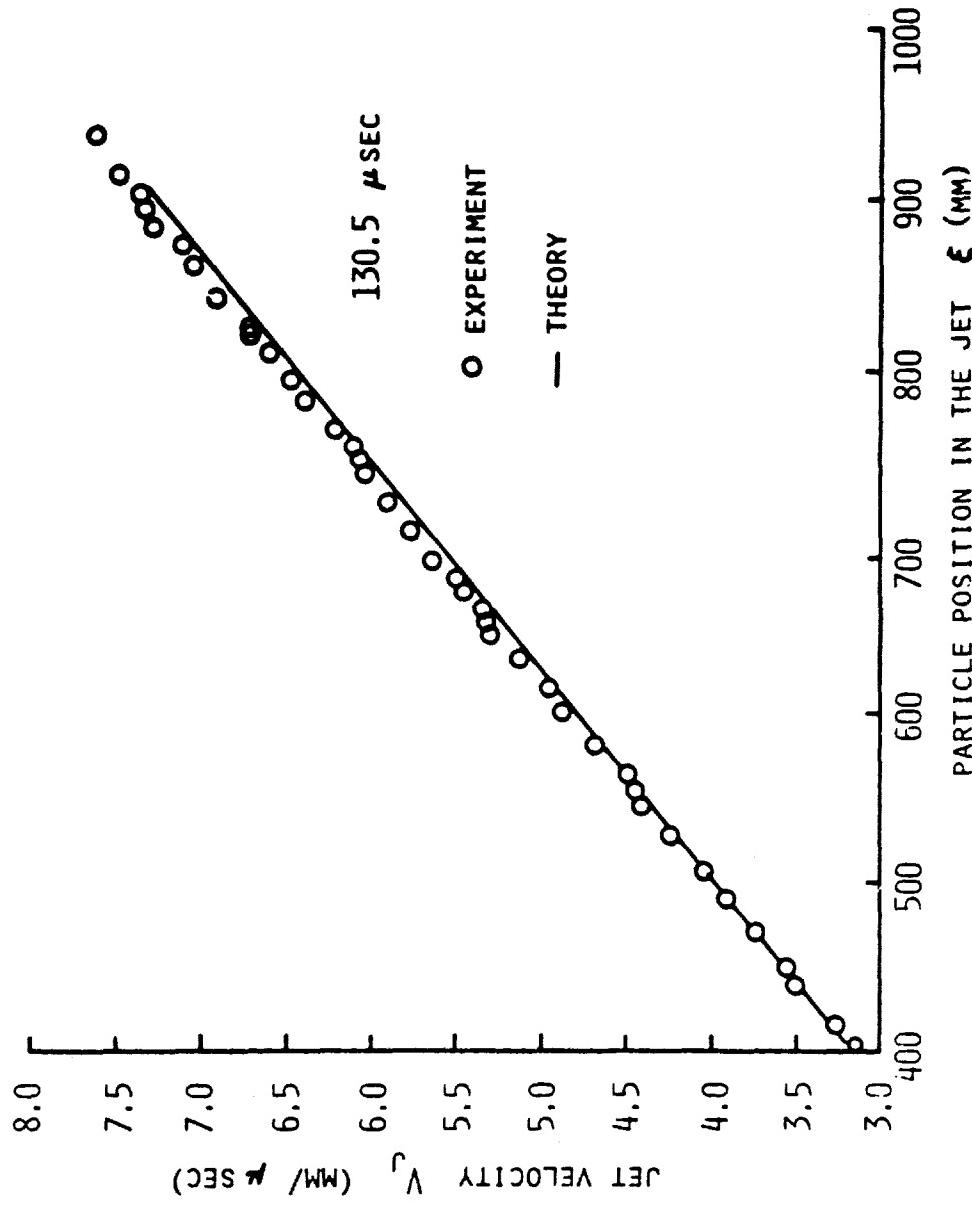


FIGURE B4. Theoretical and experimental jet velocity vs. jet particle position for the 50.8mm,  $42^\circ$ , 1.524mm wall, copper lined charge at 130.5 usec after detonation wave arrival at cone apex. (Charge No. 6)

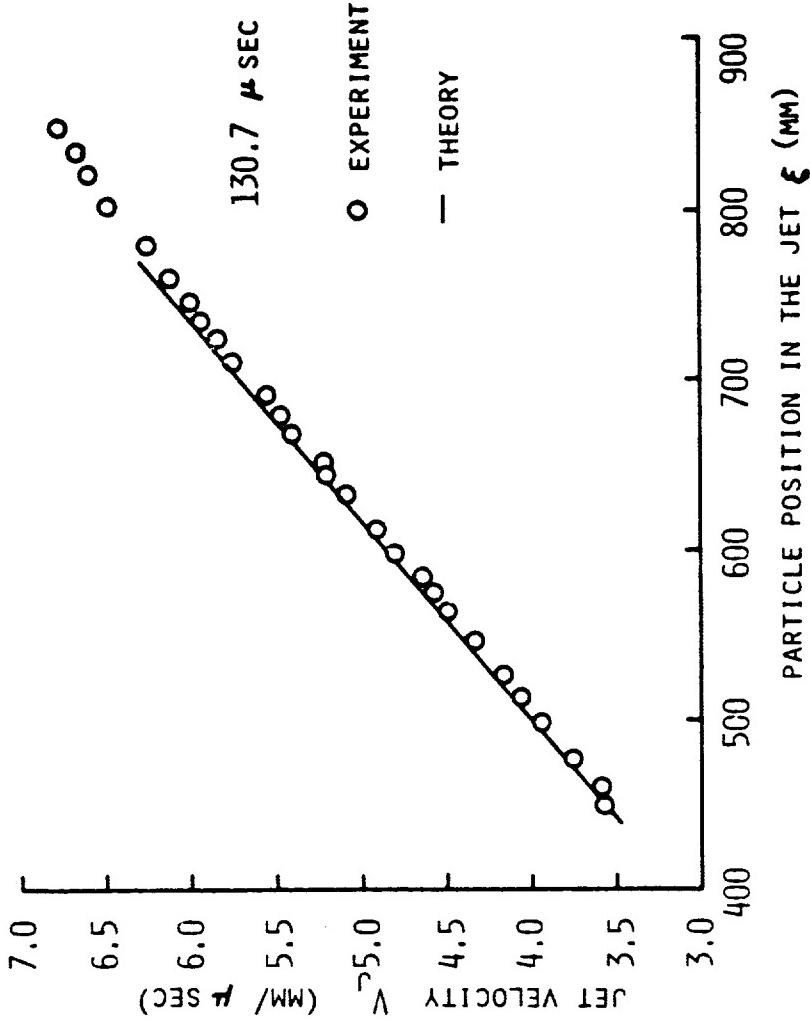


FIGURE B5. Theoretical and experimental jet velocity vs. jet particle position for the 50.8mm, 42°, 2.54mm wall, copper lined charge at 130.7  $\mu$ sec after detonation wave arrival at cone apex. (charge No. 7)

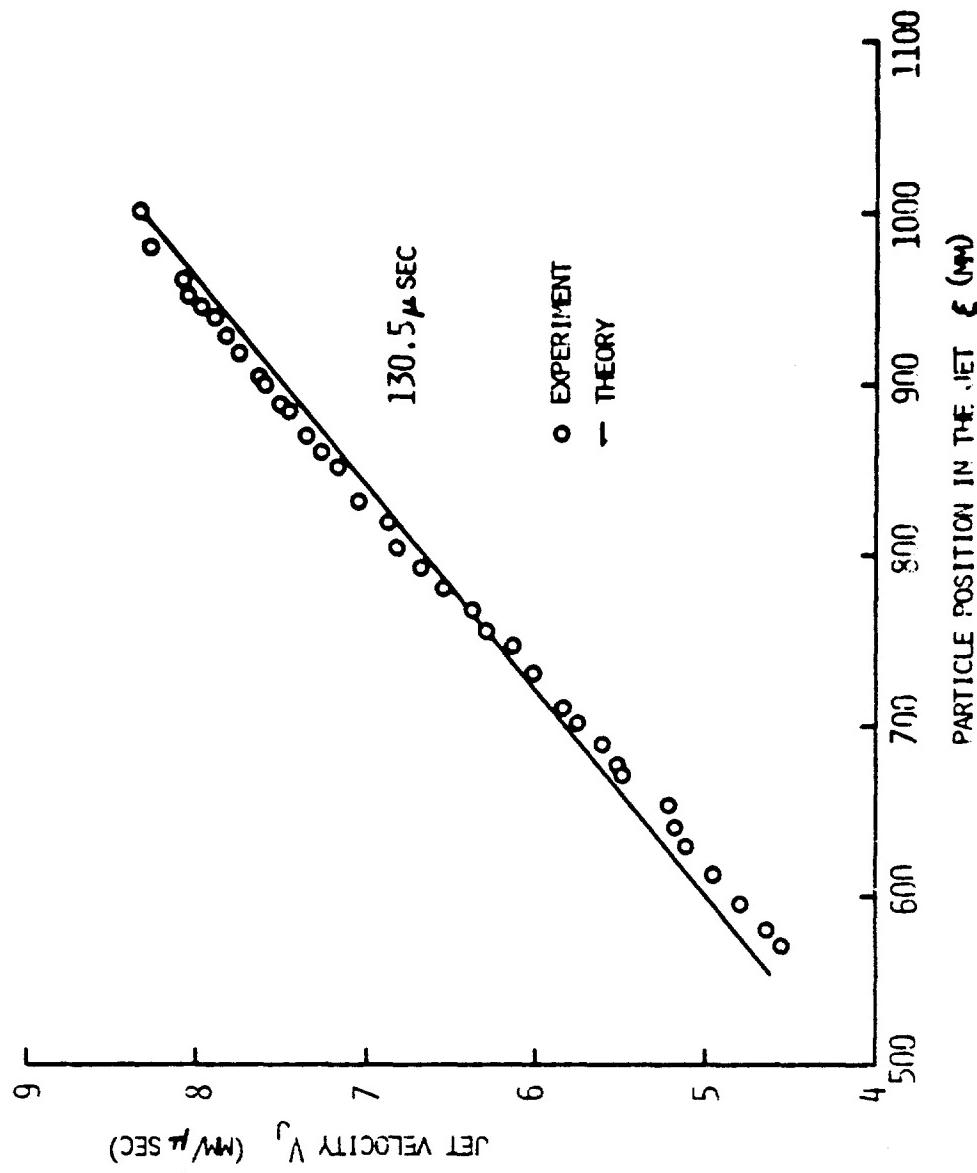


FIGURE B6. Theoretical and experimental jet velocity vs. jet particle position for the 81.3mm, 42°, tapered wall, Copper lined charge at 130.5 usec after detonation wave arrival at cone apex. (charge No. 8)

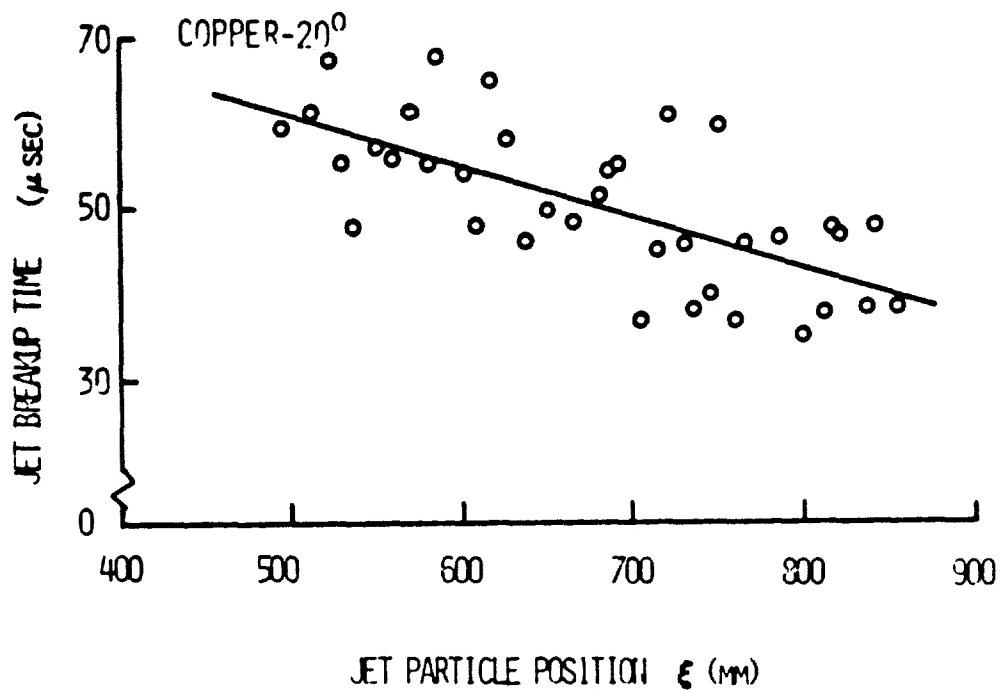


FIGURE B7. Jet breakup time vs. jet particle position at  $t=107.7 \mu$ sec for the 38.1 mm,  $20^{\circ}$ , 1.168 mm wall, copper lined charge (charge no. 1).

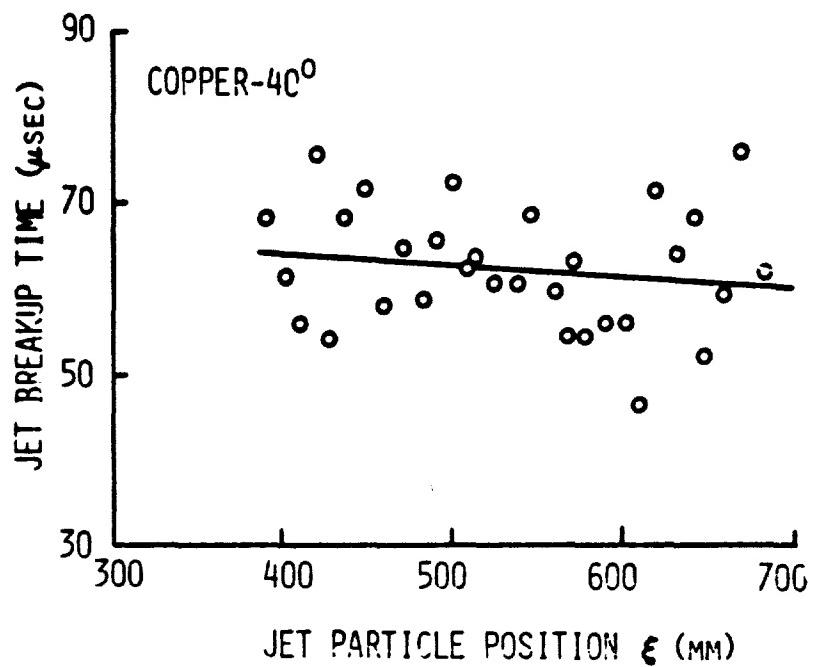


FIGURE B8. Jet breakup time vs. jet particle position at  $t=93.4$   $\mu$ sec for the 38.1mm, 40°, 1.168 mm wall copper lined charge.  
(Charge No.2)

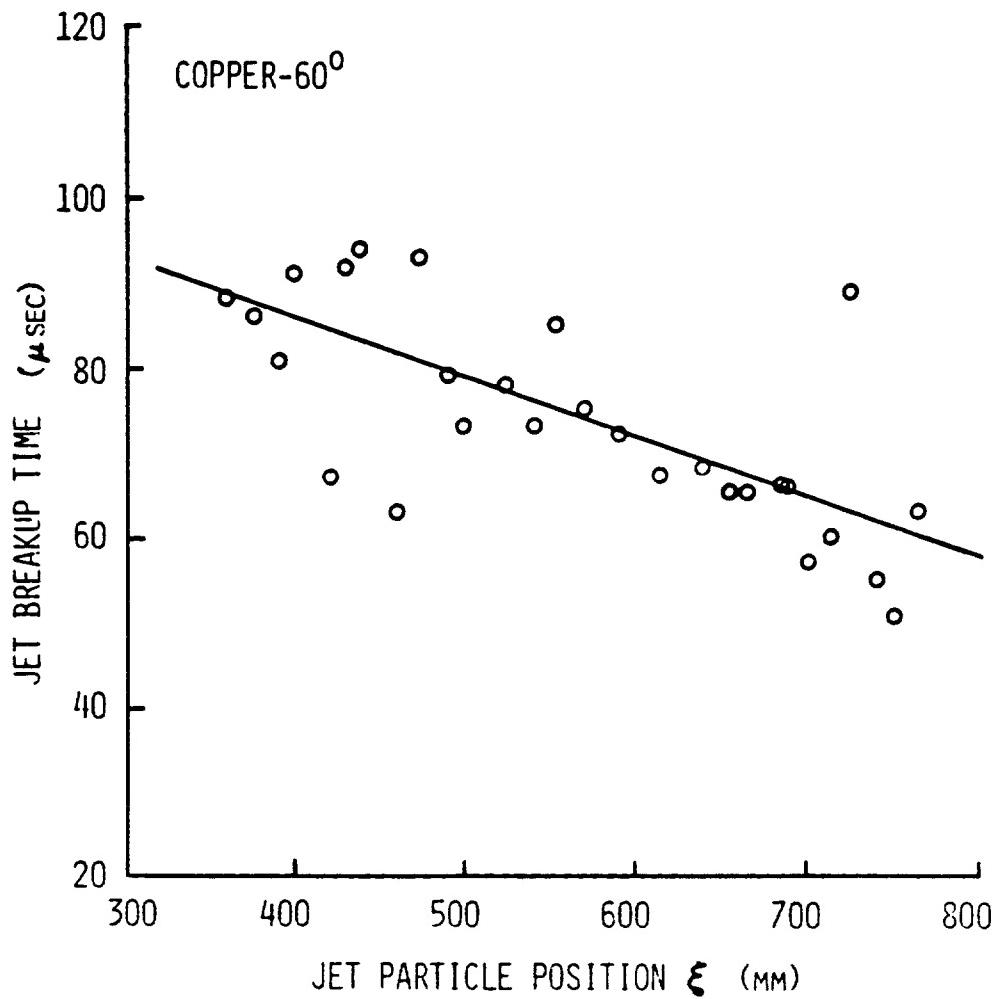


FIGURE B9. Jet breakup time vs. jet particle position at  $t=122.7 \mu\text{sec}$  for the 38.1mm, 60°, 1.168 mm wall Copper lined charge.  
(Charge No. 3)

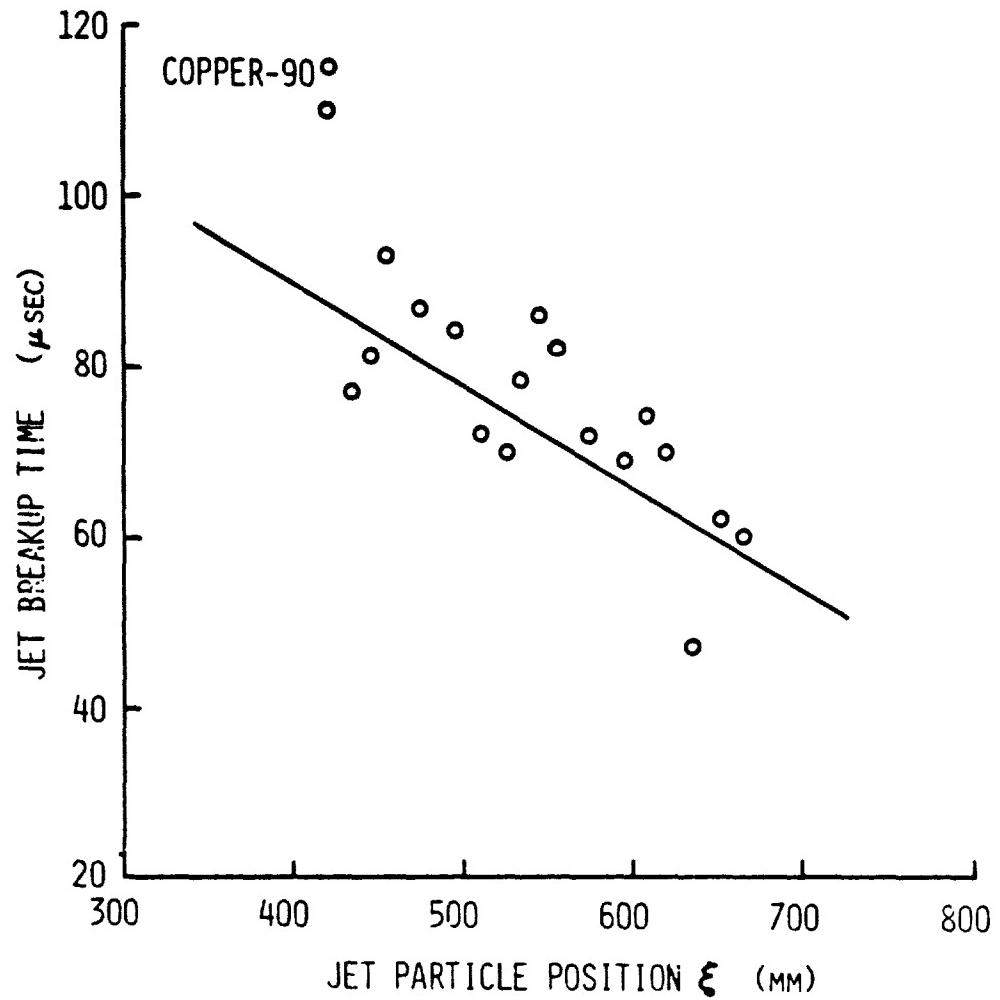


FIGURE B10. Jet breakup time vs. jet particle position at  $t=133.3 \mu\text{sec}$  for the 38.1mm, 90°, 1.168 mm wall copper lined charge.  
(Charge No. 4)

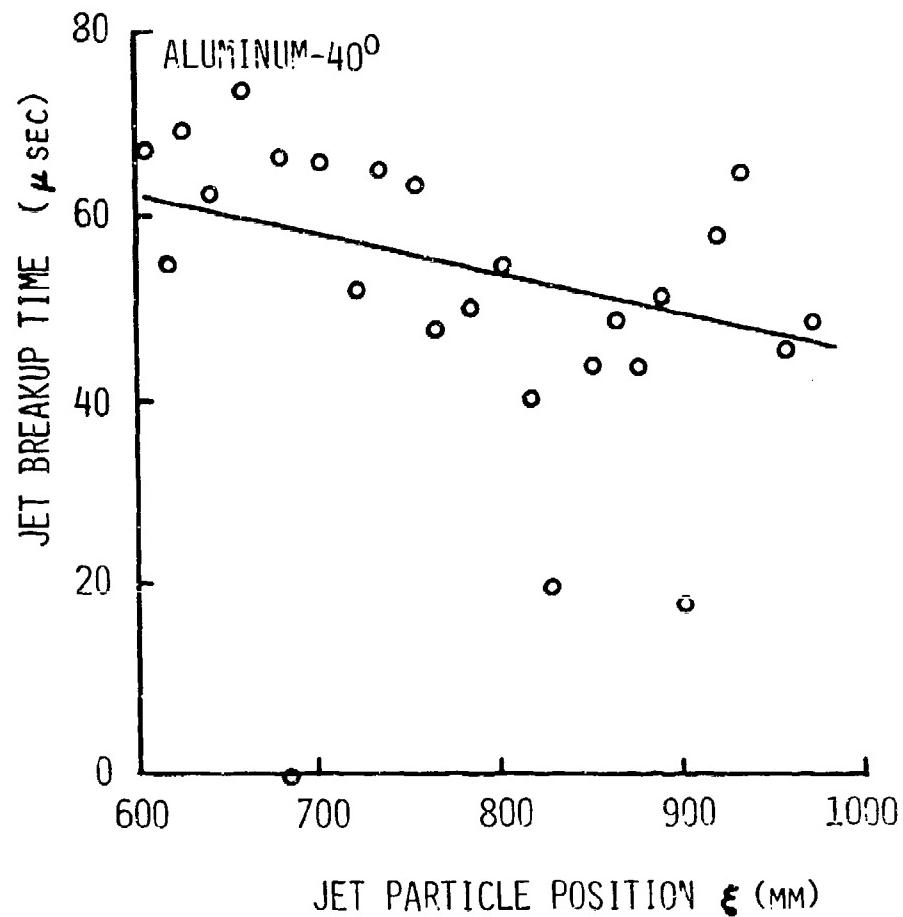


FIGURE B11. Jet breakup time vs. jet particle position at  $t=113.1 \mu$ sec for the 38.1mm,  $40^\circ$ , 1.626mm wall aluminum lined charge.  
(Charge No.9)

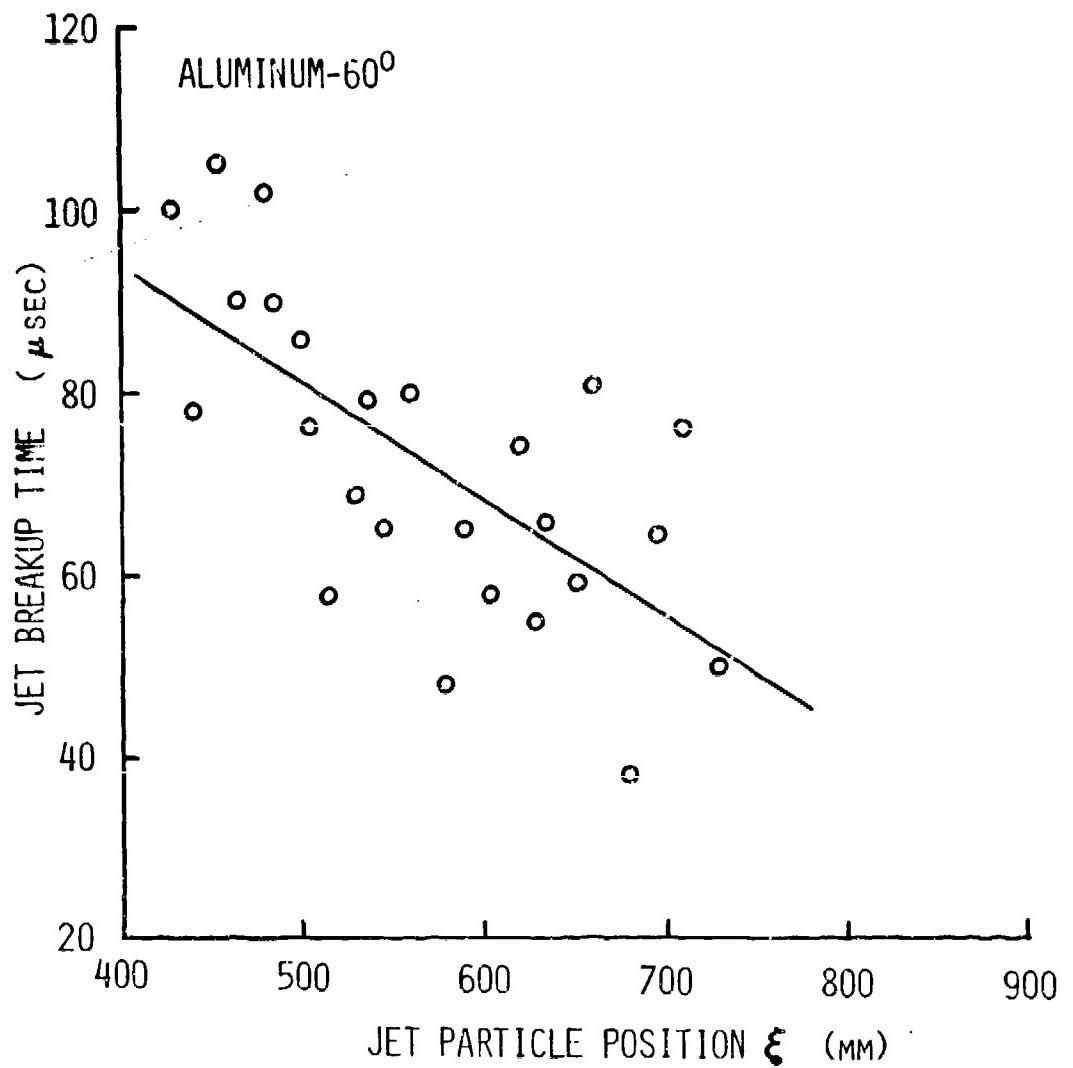


FIGURE B12. Jet breakup time vs. jet particle position at  $t=97.7 \mu\text{sec}$  for the 38.1mm, 60°, 1.626 mm wall aluminum lined charge.  
(Charge No. 10)

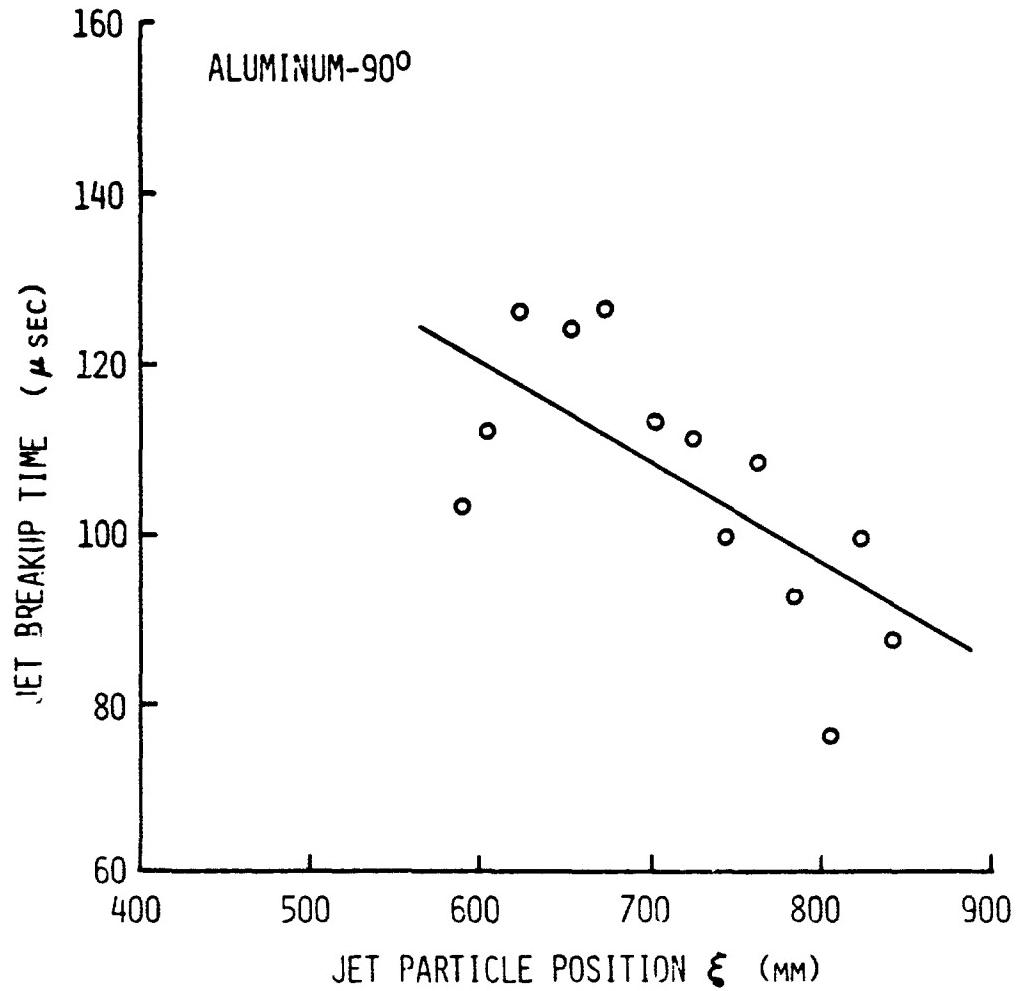


FIGURE B13. Jet breakup time vs. jet particle position at  $t=132.8 \mu\text{sec}$  for the 38.1mm, 90°, 1.626 mm wall aluminum lined charge.  
(charge No. 11)

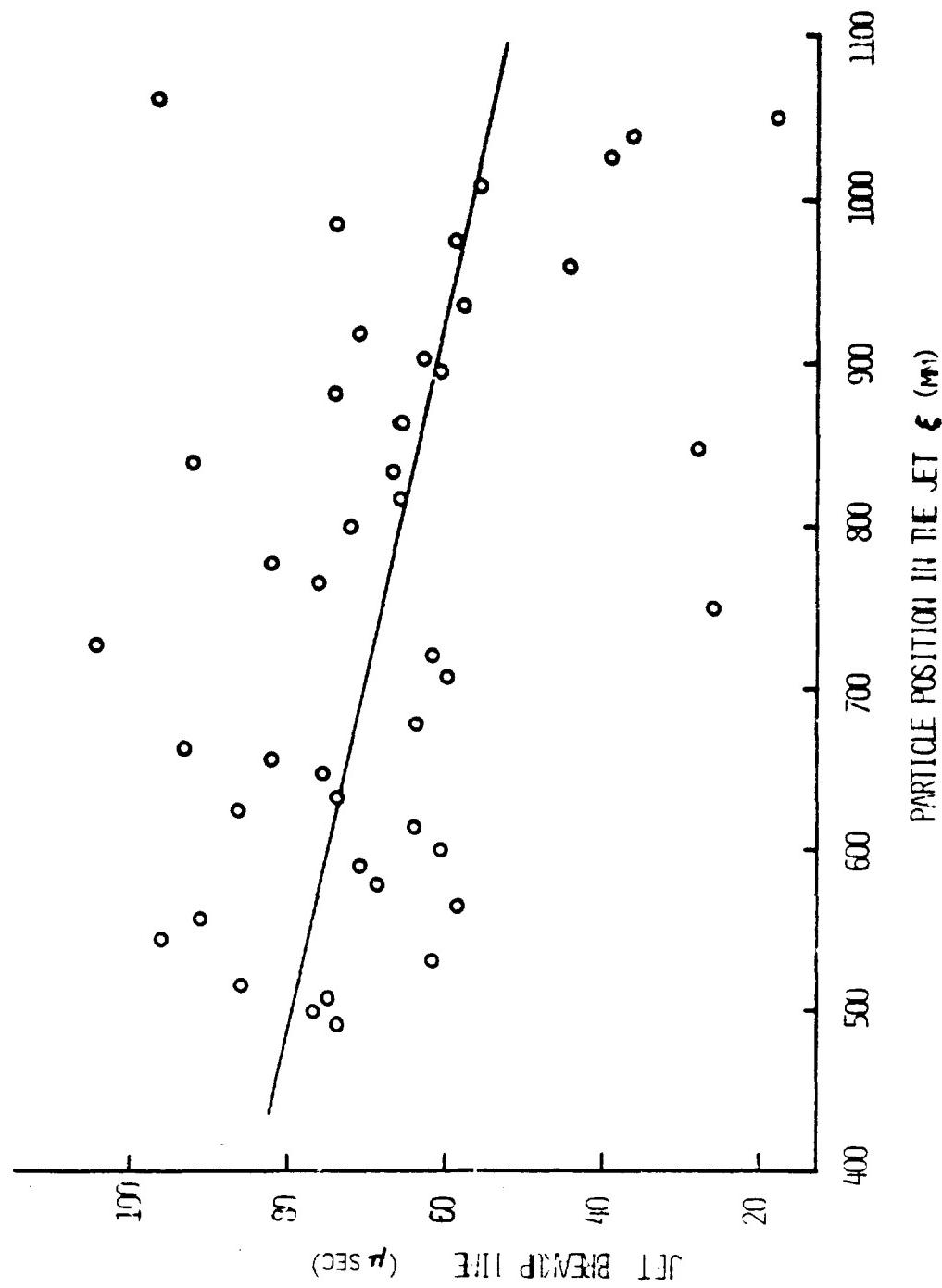


FIGURE B14. Jet breakup time vs. jet particle position at  $t=130.6 \text{ sec}$  for the 50.8 mm, 42°, 0.762 mm wall, copper lined charge (charge no. 5).

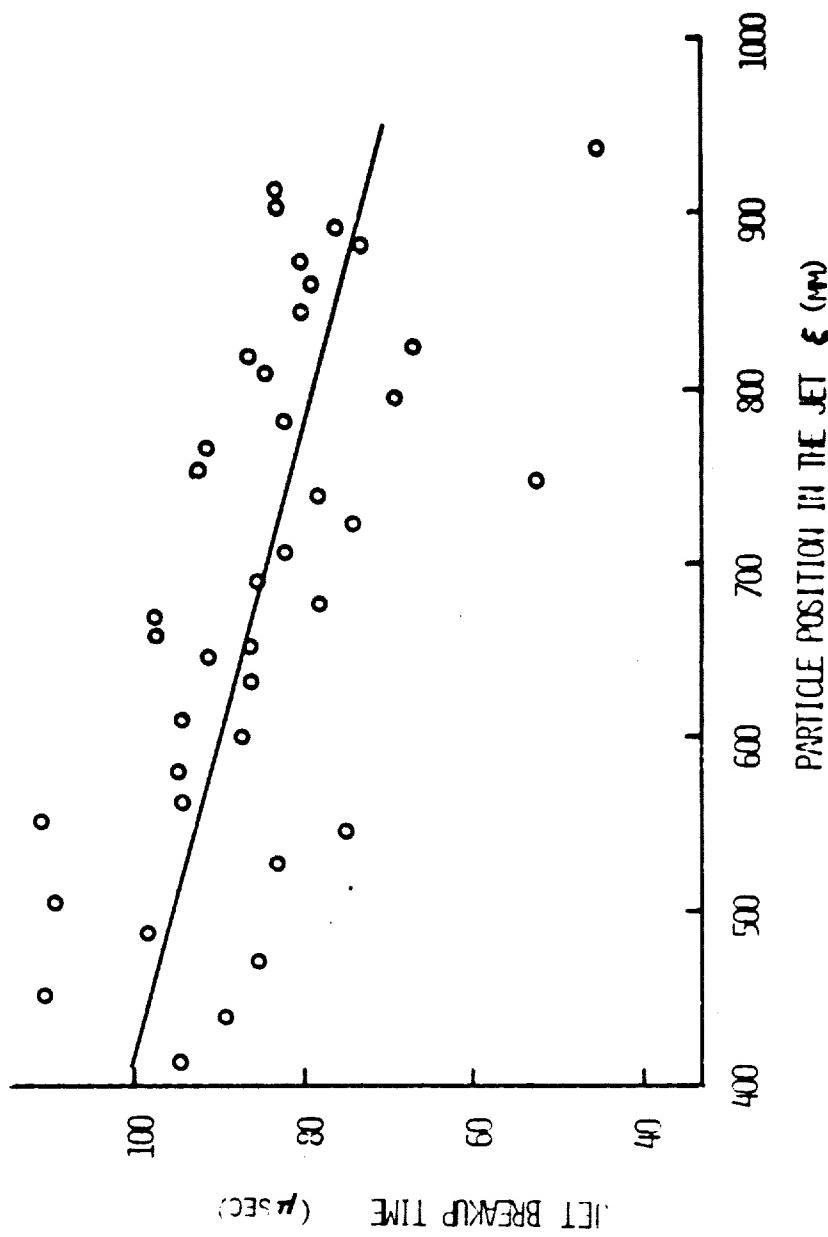


FIGURE B15. Jet breakup time vs. jet position at  $t = 130.5 \mu\text{sec}$  for the 50.8 mm, 42°, 1.524 mm wall, copper lined charge (charge no. 6).

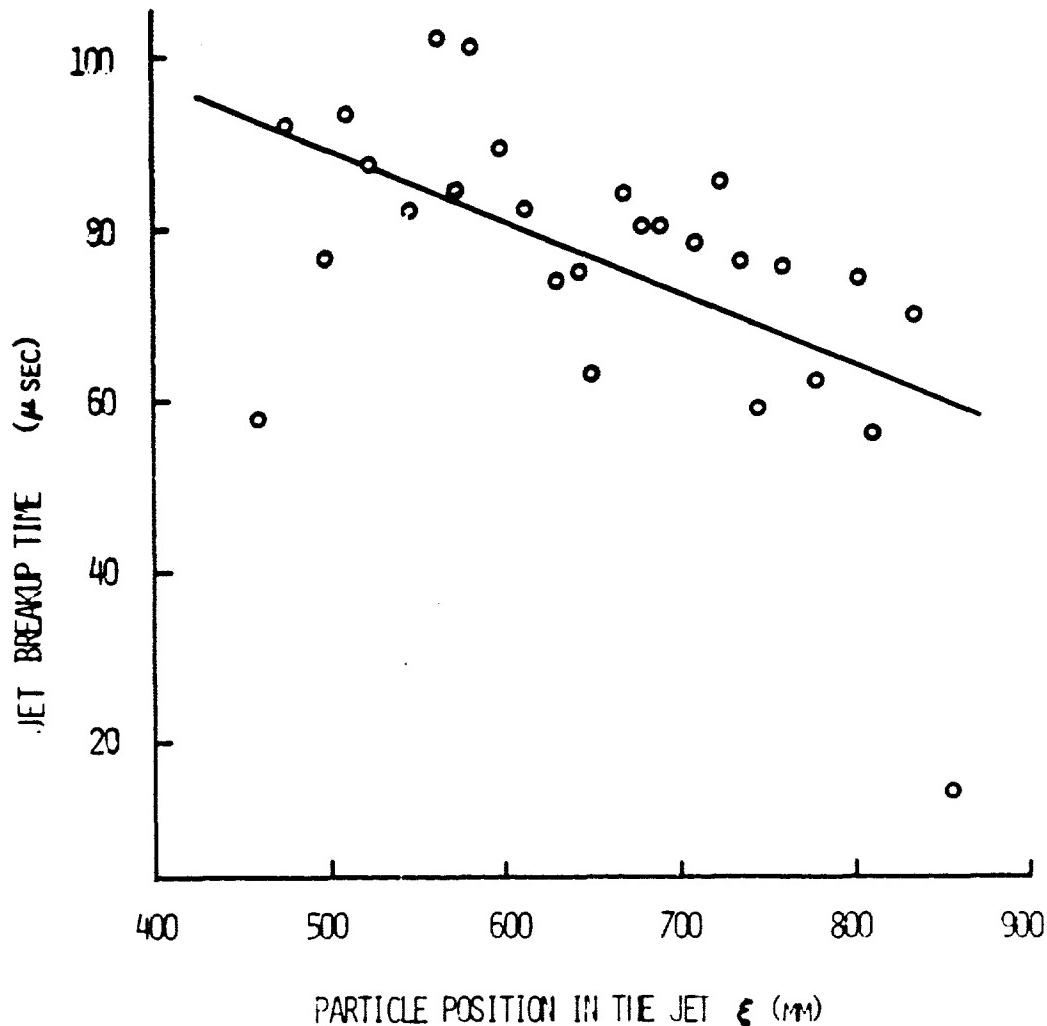


FIGURE B16. Jet breakup time vs. jet position at  $t=130.7 \mu\text{sec}$  for the 50.8 mm,  $42^\circ$ , 2.54 mm wall, copper lined charge (charge no. 7).

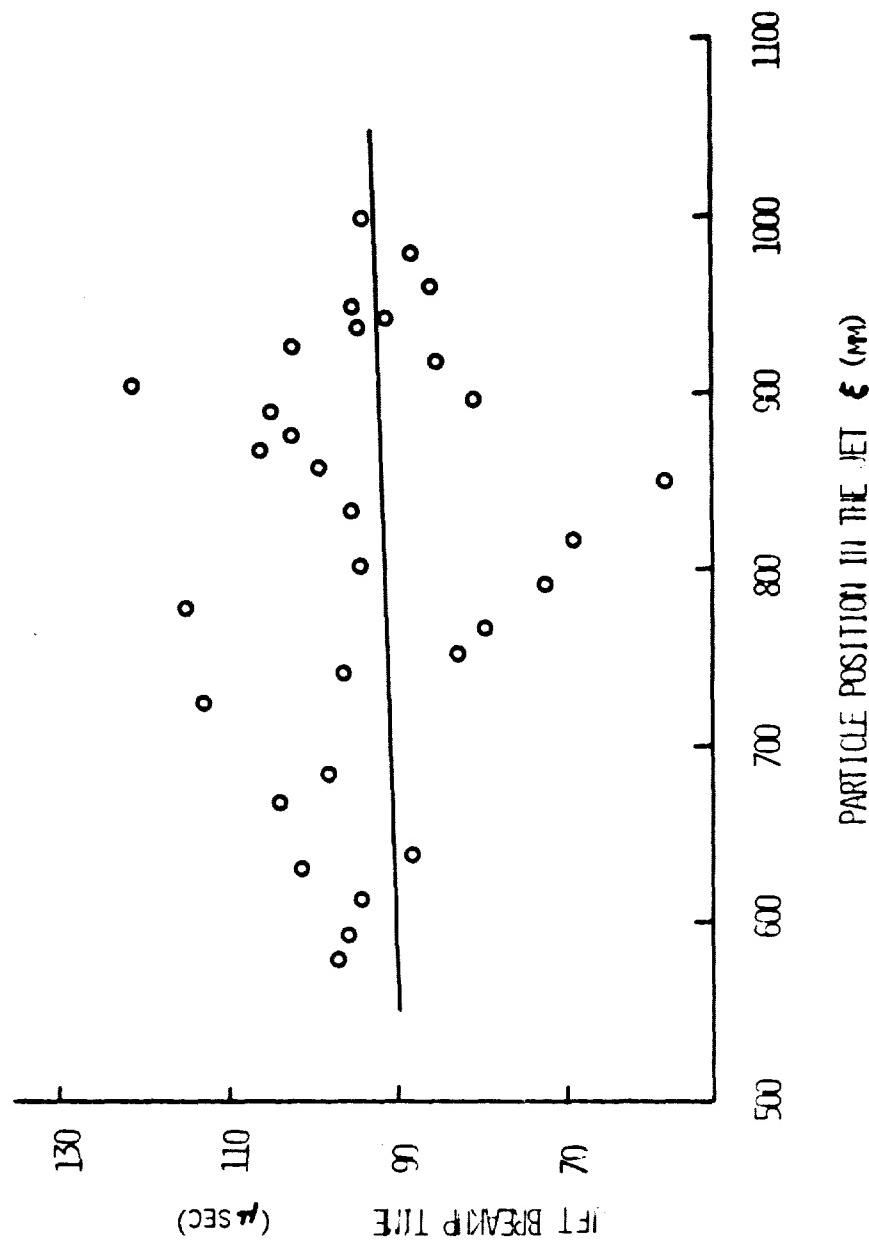


FIGURE B17. Jet breakup time vs. jet particle position  
at  $t=130.5$  usec for the 81.3 mm,  $42^\circ$ , tapered wall,  
copper lined charge (charge no. 8).

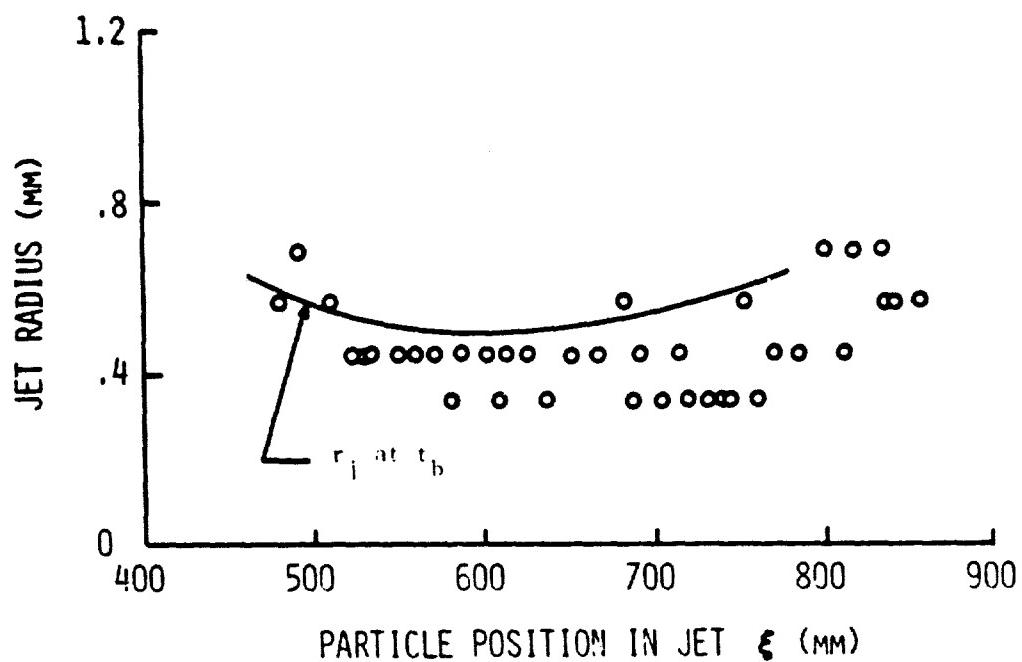


FIGURE B18. Theoretical and experimental jet radius vs. jet particle position at  $t=107.7$  usec for the 38.1 mm,  $20^\circ$ , 1.168 mm wall, copper lined charge (charge no. 1).

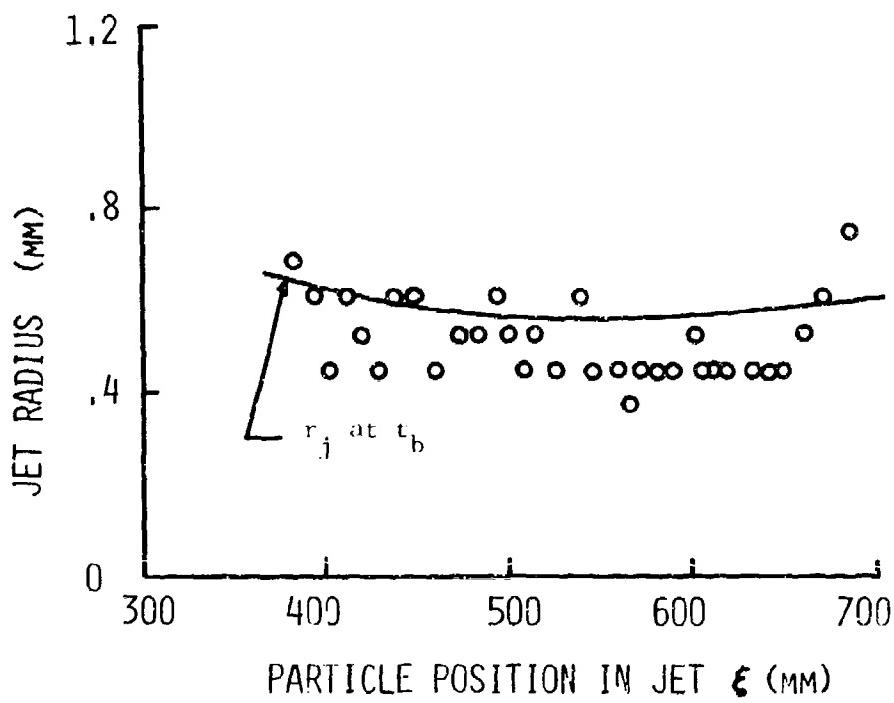


FIGURE B19. Theoretical and experimental jet radius vs. jet particle position at  $t=93.4$   $\mu$ sec for the 38.1 mm,  $40^\circ$ , 1.168 mm wall, copper lined charge (charge no. 2).

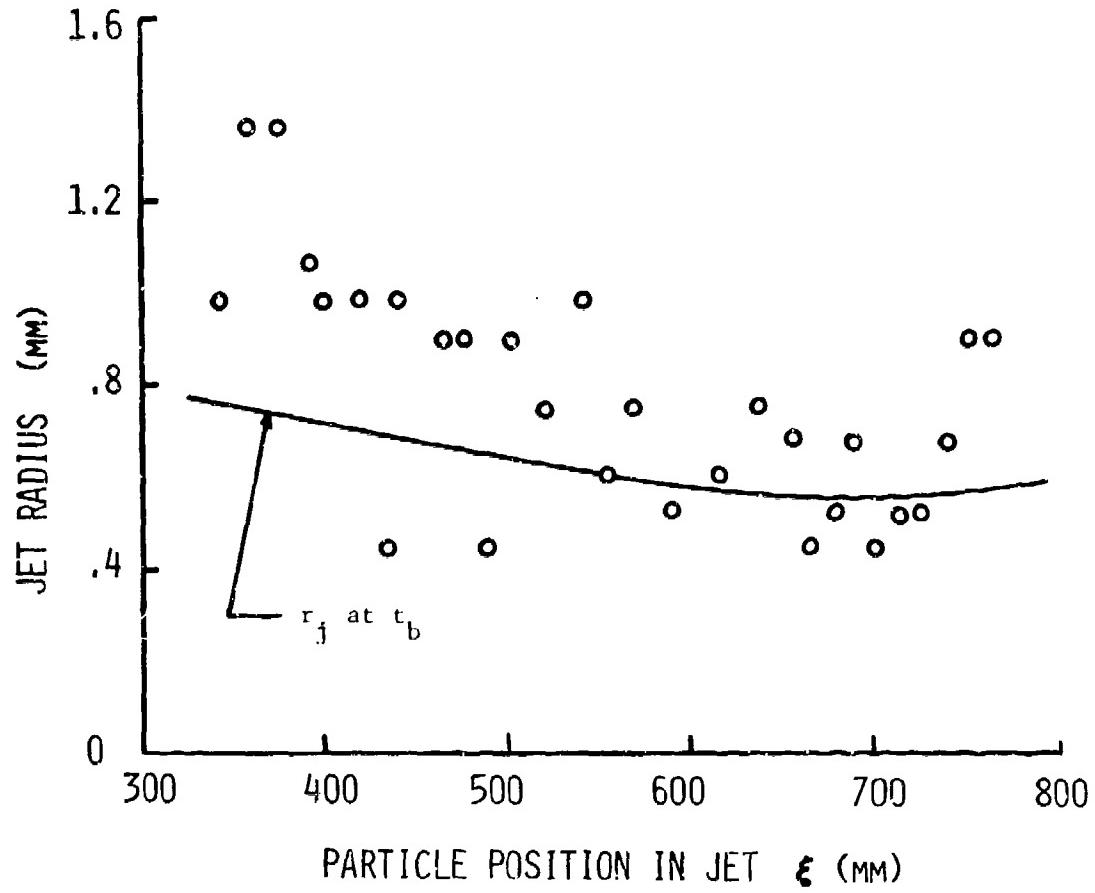


FIGURE B20. Theoretical and experimental jet radius vs. jet particle position at  $t=122.7 \mu\text{sec}$  for the 38.1 mm,  $60^\circ$ , 1.168 mm wall copper lined charge (charge no. 3).

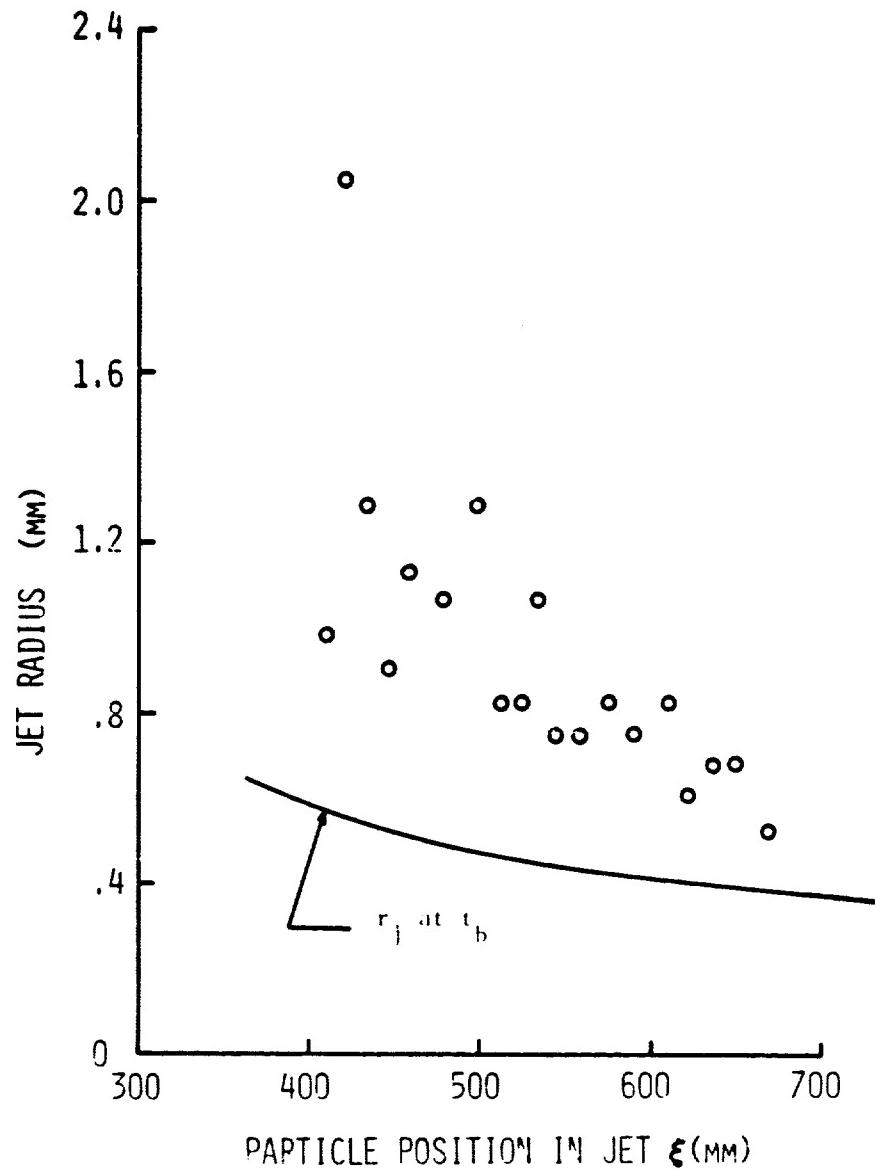


FIGURE B21. Theoretical and experimental jet radius vs. jet particle position at  $t=133.3 \mu\text{sec}$  for the 38.1 mm,  $90^\circ$ , 1.168 mm wall copper lined charge (charge no. 4).

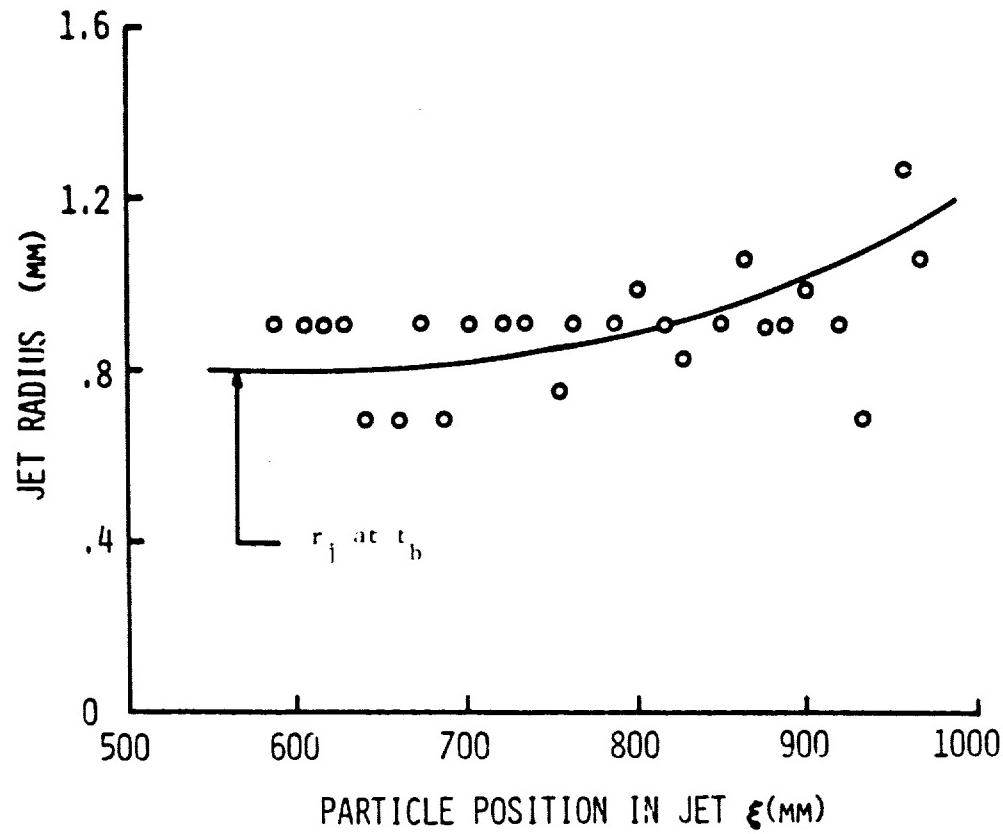


FIGURE B22. Theoretical and experimental jet radius vs. jet particle position at  $t=113.1 \mu\text{sec}$  for the 38.1 mm,  $40^\circ$ , 1.626 mm wall aluminum lined charge (charge no. 9).

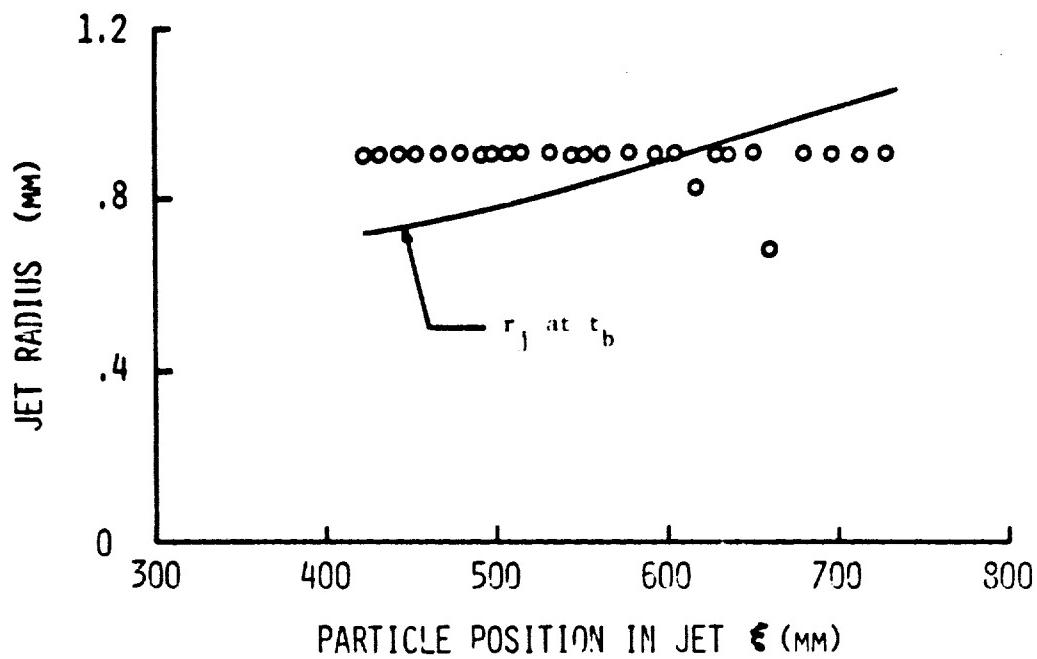


FIGURE B23. Theoretical and experimental jet radius vs. jet particle position at  $t=97.7$  usec for the 38.1 mm,  $60^\circ$ , 1.626 mm wall aluminum lined charge (charge no. 10).

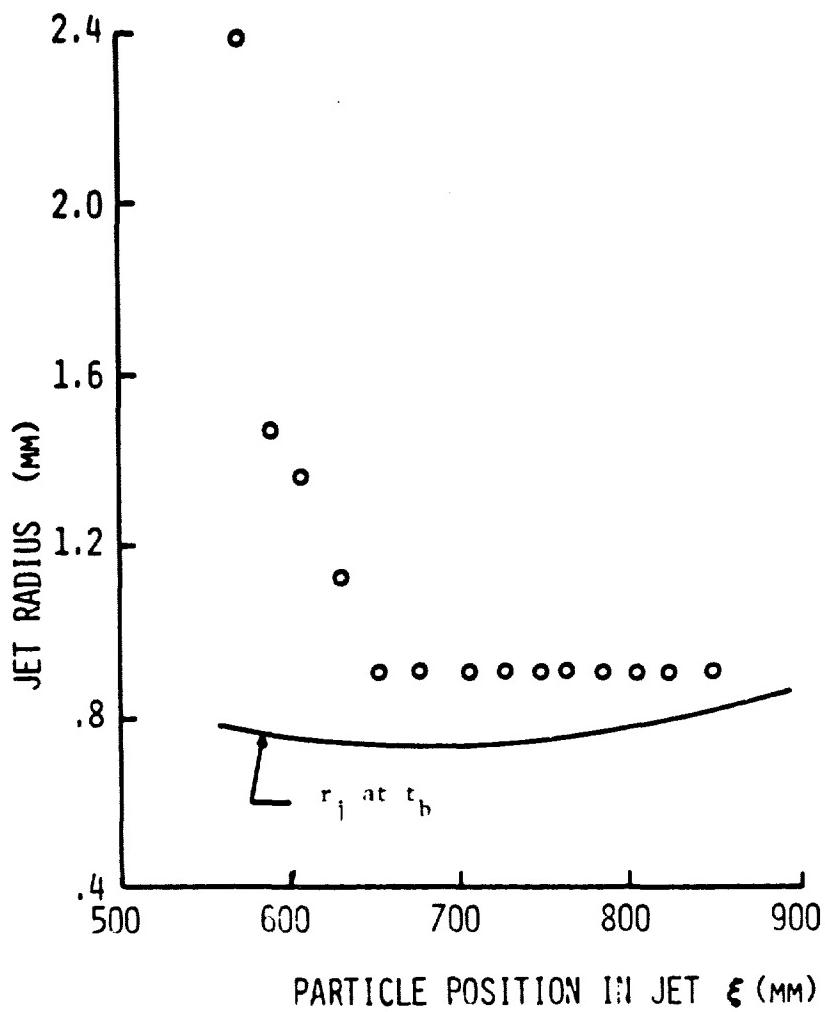


FIGURE B24. Theoretical and experimental jet radius vs. jet particle position at  $t=132.8 \mu\text{sec}$  for the 38.1 mm,  $90^\circ$ , 1.626 mm wall aluminum lined charge (charge no. 11).

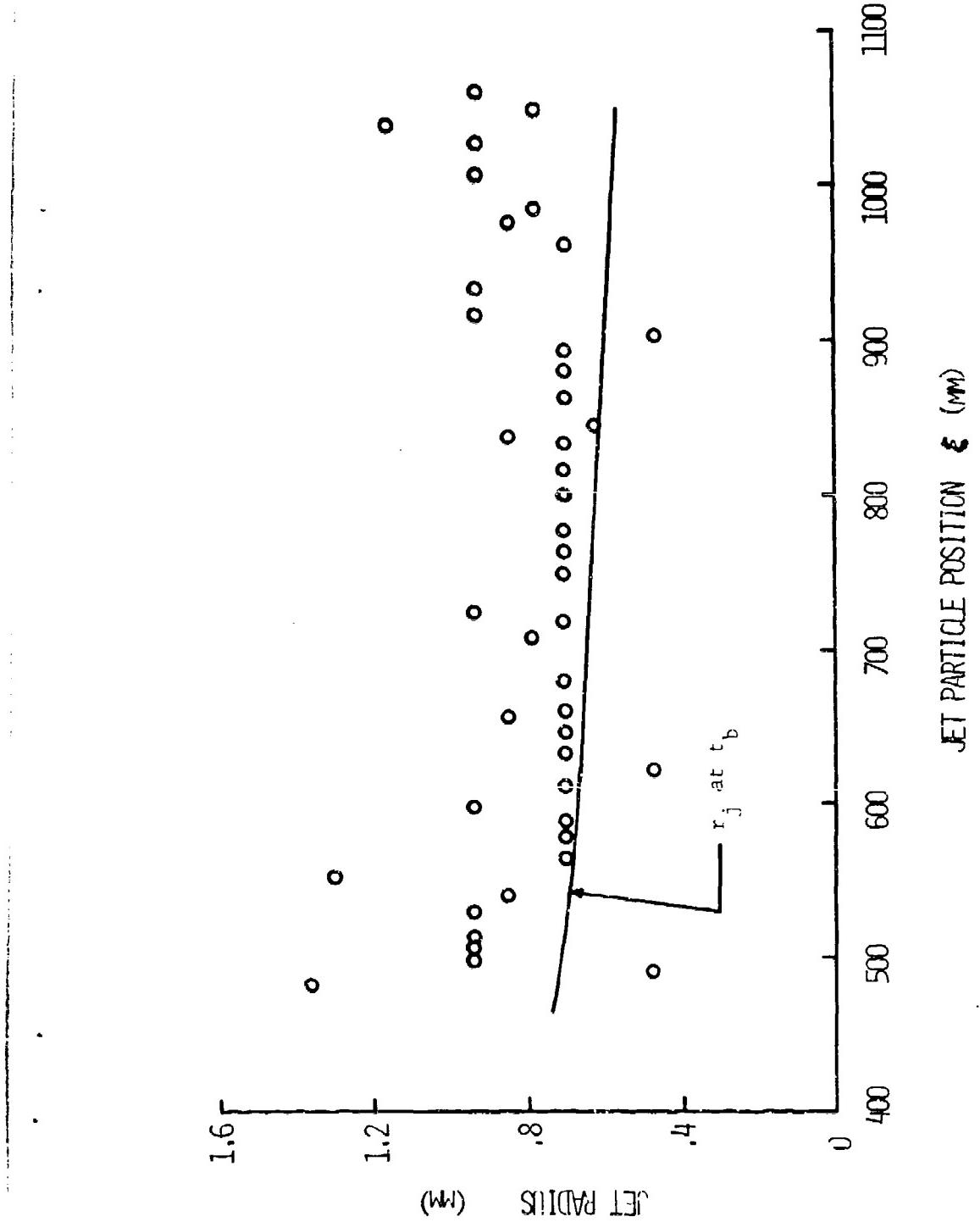


FIGURE 325. Theoretical and experimental jet radius vs. jet particle position at  $t=130.6 \mu\text{sec}$  for the 50.8 mm,  $42^\circ$ , 0.762 mm wall copper lined charge (charge no. 5).

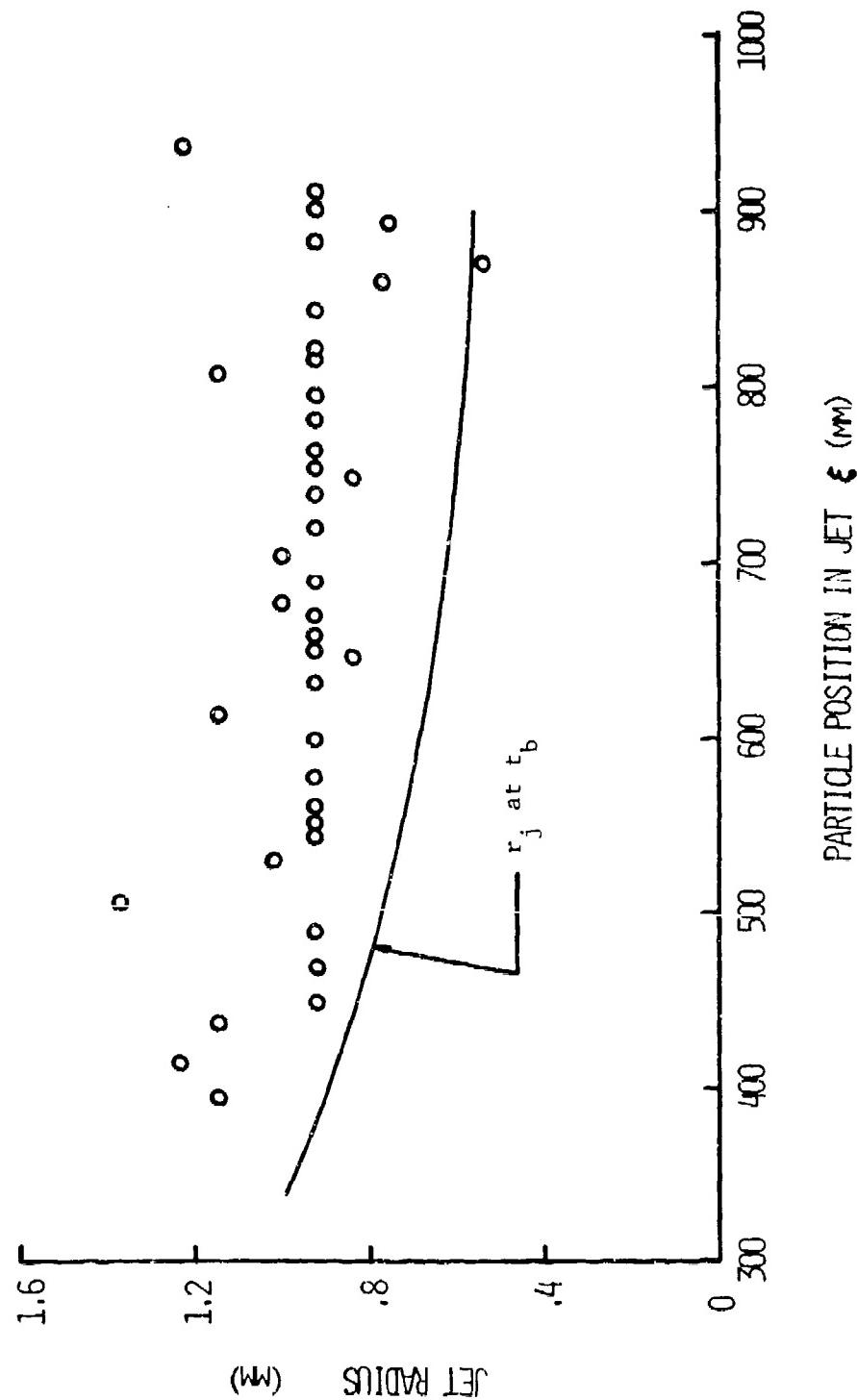


FIGURE B26. Theoretical and experimental jet radius vs. jet particle position at  $t=130.5 \mu\text{sec}$  for the 50.8 mm, 42°, 1.524 mm wall copper lined charge (charge no. 6).

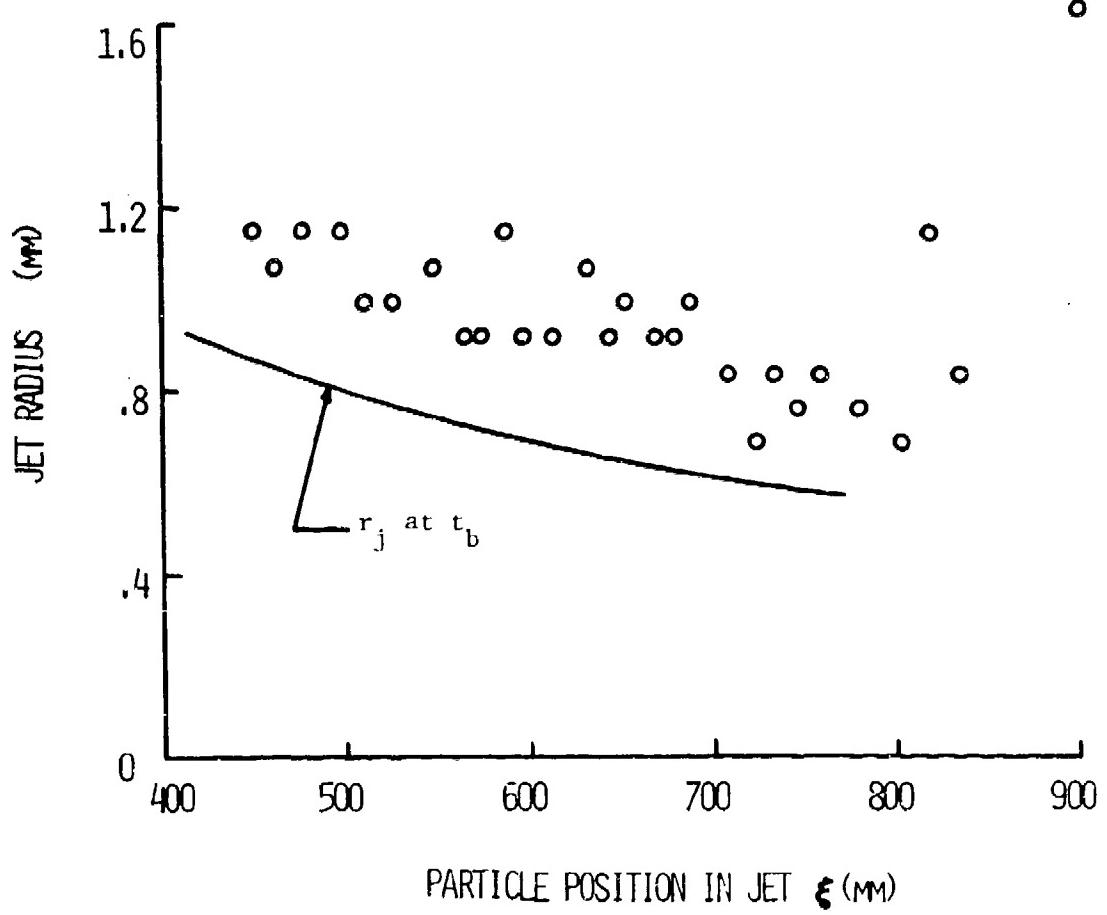


FIGURE B27. Theoretical and experimental jet radius vs. jet particle position at  $t=130.7 \mu\text{sec}$  for the 50.8 mm,  $42^\circ$ , 2.54 mm wall copper lined charge (charge no. 7).

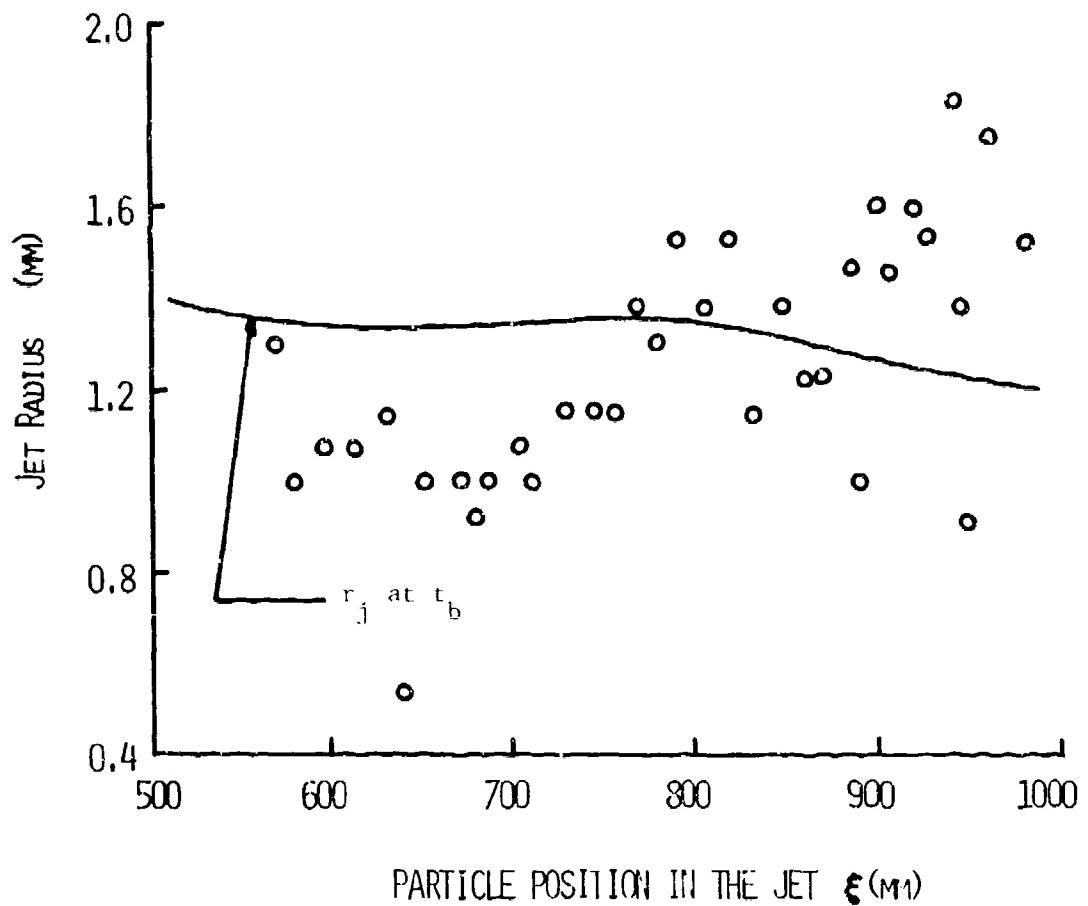


FIGURE B28. Theoretical and experimental jet radius vs. jet particle position at  $t=130.5$   $\mu$ sec for the 81.3 mm  $42^\circ$ , tapered wall copper lined charge (charge no. 8). (Note: The lead particle at 1003 mm in the jet has a radius of 4.6 mm and is not plotted here for convenience.)

### Appendix C

This appendix contains tabulated data for the jet velocity, break-up time, length, diameter, radius, aspect ratio and  $\Delta V_j$  of the jet segments as computed from radiograph measurements for the eleven charges studied in this report.

The breakup times in these tables are referred to  $t=0$  when the charge is first initiated. Throughout the rest of the report, including the plots of appendix B, all times are referred to  $t=0$  when the detonation wave first reaches the apex of the liner cone. The time it takes for the wave to travel from the point of initiation to the apex of the cone for charges 5,6 and 7 is  $6.4\mu\text{sec}$ ; for all other charges this time is  $7.0\mu\text{sec}$ .

CHANNEL NO. 1 • 30.1 MM. 20 DEGREE. 1.160 MH KALL. CLIPPER LINE 21

ALL VALUES ARE THE AVERAGE FROM THREE HAVIJUKAPHS

**STANLEY OVIATIUM**

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CHANGE NU. 2. 30.1 MM, 40 DEGREE, 1.165 MM WALL, COMPLEX LINES

ALL VALUES ARE THE AVERAGE FROM THREE RADIOPHOTOMAPS

NU.	VELLUTY MM/MACKJULC	DU TIME MICROSEC.	LENGTH MM.	DIA METER MM.	MAGNITUDE MM.	L/U RATIO	VEL CHANGE
1	0.01237E 01	0.06930E 01	4.05167E 01	1.51667E 00	7.54334E -01	7.58333E 00	1.21496E -01
2	0.06007E 01	0.29701E 01	1.03727E 01	1.21133E 00	6.06667E -01	9.55556E 00	7.6294E -02
3	0.70324E 00	0.63635E 01	2.40000E 00	1.06167E 00	5.30333E -01	5.22222E 00	1.25260E -01
4	0.32790E 00	5.89660E 01	4.08233E 00	1.00000E -01	4.05000E -01	5.33333E 00	2.03450E -02
5	0.59454E 00	7.52071E 01	3.91200E 00	9.10000E -01	4.50000E -01	6.50000E 00	1.34444E -01
6	0.40214E 00	7.10273E 01	7.43167E 00	9.10000E -01	4.50000E -01	6.16667E 00	1.05152E -01
7	0.32970E 00	7.42636E 01	1.00101E 01	9.10000E -01	4.50000E -01	1.01000E 01	1.04460E -01
8	0.10449E 01	5.360095E 01	1.40834E 00	9.10000E -01	4.50000E -01	1.09333E 00	4.35016E -02
9	0.14136E 01	4.68106E 01	2.57033E 00	9.10000E -01	4.50000E -01	2.03333E 00	3.51610E -02
10	0.10022E 01	6.34329E 01	3.74433E 00	9.10000E -01	4.50000E -01	1.06667E 00	1.05260E -01
11	0.04262E 01	6.12801E 01	7.12950E 00	9.10000E -01	4.50000E -01	1.05000E 00	1.02360E -01
12	0.03473E 01	6.12913E 01	4.24000E 00	9.10000E -01	4.50000E -01	4.06667E 00	6.72049E -02
13	0.76222E 01	7.40251E 01	3.19500E 00	9.10000E -01	4.50000E -01	1.05000E 00	9.27966E -02
14	0.67272E 01	6.15144E 01	1.16200E 00	7.50333E -01	1.74167E 01	1.83333E 00	4.05279E -02
15	0.06244E 01	0.65555E 01	9.44333E 00	9.10000E -01	4.50000E -01	1.05000E 01	1.04725E -01
16	0.45971E 00	7.55164E 01	2.35633E 00	9.10000E -01	4.50000E -01	1.05000E 00	1.04633E -01
17	0.34615E 00	6.77465E 01	6.02200E 00	1.21133E 00	0.06667E 01	1.05000E 00	1.06215E -01
18	0.10694E 00	6.76662E 01	7.07030E 00	9.43333E 00	4.50000E -01	1.05000E 01	1.05375E -01
19	0.005260E 01	7.07330E 01	4.19050E 00	1.06167E 01	7.00000E 01	4.22222E 00	5.74444E -02
20	0.64622E 01	0.46794E 01	2.57033E 00	9.10000E -01	4.50000E -01	2.03333E 00	1.05000E 01
21	0.005012E 01	7.92796E 01	7.43167E 00	1.06167E 01	5.00000E 01	7.22222E 00	8.00000E -02
22	0.77777E 01	7.26510E 01	4.08233E 00	1.21133E 00	0.06667E 01	4.05556E 00	1.04460E -01
23	0.66326E 01	6.57557E 01	6.08667E 00	1.06167E 01	7.00000E 01	5.77775E 00	1.00000E 01
24	0.50315E 01	7.16744E 01	7.05000E 01	1.06167E 00	2.03333E 01	7.66667E 00	1.06667E -01
25	0.49032E 01	6.44654E 01	6.12200E 00	9.10000E -01	4.50000E -01	7.50000E 00	1.05430E -01
26	0.244221E 00	7.04110E 01	7.12033E 00	1.21133E 00	0.06667E 01	6.11111E 00	1.028775E -01
27	0.11349E 00	7.00339E 01	4.23167E 00	1.21133E 00	0.06667E 01	7.00000E 00	1.04460E -01
28	0.02239E 00	6.10495E 01	2.70333E 00	9.10000E -01	4.50000E -01	3.00000E 00	1.02762E -01
29	4.9423142E 01	6.26067E 01	6.67333E 00	1.06167E 00	2.03333E 01	6.44444E 00	1.01263E -01
30	4.01049E 01	6.30417E 01	5.01672E 00	1.21133E 00	0.06667E 01	4.77775E 00	7.29116E -02
31	4.07356E 01	6.91429E 01	3.64000E 00	9.10000E -01	4.50000E -01	4.00000E 00	1.05635E -01
32	4.60120E 01	7.52378E 01	6.79197E 00	1.21133E 00	0.06667E 01	7.11111E 00	1.04770E -01
33	4.04355E 01	AXXXXXXXAXX	6.07333E 00	1.36500E 00	6.02500E 01	4.066669E 00	XXXXXXKXXX
AVERAGE =	0.052266E 01	6.10149E 01	1.03409E 00	5.017045E 01	5.94333E 00	1.11219E -01	3.06551E -01

STANDARD DEVIATION  
COEFF. OF VARIATION

7.44723E 00  
0.113392E -01

4.07664E 00  
3.06551E -01

## CHANNEL NO. 30, 30.1 MM, 60' LENGTH, 1.069 MM WALL, CURVED LINE

## ALL VALUES ARE IN FEET FROM FLOOR JOINT TO PUMP

NU.	STRUCTURE IN CHANNEL	NO. LINE	LEADIN ANG.	DIA. IN MM.	LEADERS	ANG.	L/D RATIO	W/L LENGTH
1	0.007001	JU	0.007001	.31	0.007001	0.0	0.014091	0.0
2	0.007002	JU	0.007002	.31	0.007002	0.0	0.008751	0.0
3	0.007003	JU	0.007003	.31	0.007003	0.0	0.002222	0.0
4	0.007004	JU	0.007004	.31	0.007004	0.0	0.002222	0.0
5	0.007005	JU	0.007005	.31	0.007005	0.0	0.002222	0.0
6	0.007006	JU	0.007006	.31	0.007006	0.0	0.002222	0.0
7	0.007007	JU	0.007007	.31	0.007007	0.0	0.002222	0.0
8	0.007008	JU	0.007008	.31	0.007008	0.0	0.002222	0.0
9	0.007009	JU	0.007009	.31	0.007009	0.0	0.002222	0.0
10	0.007010	JU	0.007010	.31	0.007010	0.0	0.002222	0.0
11	0.007011	JU	0.007011	.31	0.007011	0.0	0.002222	0.0
12	0.007012	JU	0.007012	.31	0.007012	0.0	0.002222	0.0
13	0.007013	JU	0.007013	.31	0.007013	0.0	0.002222	0.0
14	0.007014	JU	0.007014	.31	0.007014	0.0	0.002222	0.0
15	0.007015	JU	0.007015	.31	0.007015	0.0	0.002222	0.0
16	0.007016	JU	0.007016	.31	0.007016	0.0	0.002222	0.0
17	0.007017	JU	0.007017	.31	0.007017	0.0	0.002222	0.0
18	0.007018	JU	0.007018	.31	0.007018	0.0	0.002222	0.0
19	0.007019	JU	0.007019	.31	0.007019	0.0	0.002222	0.0
20	0.007020	JU	0.007020	.31	0.007020	0.0	0.002222	0.0
21	0.007021	JU	0.007021	.31	0.007021	0.0	0.002222	0.0
22	0.007022	JU	0.007022	.31	0.007022	0.0	0.002222	0.0
23	0.007023	JU	0.007023	.31	0.007023	0.0	0.002222	0.0
24	0.007024	JU	0.007024	.31	0.007024	0.0	0.002222	0.0
25	0.007025	JU	0.007025	.31	0.007025	0.0	0.002222	0.0
26	0.007026	JU	0.007026	.31	0.007026	0.0	0.002222	0.0
27	0.007027	JU	0.007027	.31	0.007027	0.0	0.002222	0.0
28	0.007028	JU	0.007028	.31	0.007028	0.0	0.002222	0.0
29	0.007029	JU	0.007029	.31	0.007029	0.0	0.002222	0.0
30	0.007030	JU	0.007030	.31	0.007030	0.0	0.002222	0.0
31	0.007031	JU	0.007031	.31	0.007031	0.0	0.002222	0.0
32	0.007032	JU	0.007032	.31	0.007032	0.0	0.002222	0.0
33	0.007033	JU	0.007033	.31	0.007033	0.0	0.002222	0.0
34	0.007034	JU	0.007034	.31	0.007034	0.0	0.002222	0.0
35	0.007035	JU	0.007035	.31	0.007035	0.0	0.002222	0.0
36	0.007036	JU	0.007036	.31	0.007036	0.0	0.002222	0.0
37	0.007037	JU	0.007037	.31	0.007037	0.0	0.002222	0.0
38	0.007038	JU	0.007038	.31	0.007038	0.0	0.002222	0.0
39	0.007039	JU	0.007039	.31	0.007039	0.0	0.002222	0.0
40	0.007040	JU	0.007040	.31	0.007040	0.0	0.002222	0.0
41	0.007041	JU	0.007041	.31	0.007041	0.0	0.002222	0.0
42	0.007042	JU	0.007042	.31	0.007042	0.0	0.002222	0.0
43	0.007043	JU	0.007043	.31	0.007043	0.0	0.002222	0.0
44	0.007044	JU	0.007044	.31	0.007044	0.0	0.002222	0.0
45	0.007045	JU	0.007045	.31	0.007045	0.0	0.002222	0.0
46	0.007046	JU	0.007046	.31	0.007046	0.0	0.002222	0.0
47	0.007047	JU	0.007047	.31	0.007047	0.0	0.002222	0.0
48	0.007048	JU	0.007048	.31	0.007048	0.0	0.002222	0.0
49	0.007049	JU	0.007049	.31	0.007049	0.0	0.002222	0.0
50	0.007050	JU	0.007050	.31	0.007050	0.0	0.002222	0.0
51	0.007051	JU	0.007051	.31	0.007051	0.0	0.002222	0.0
52	0.007052	JU	0.007052	.31	0.007052	0.0	0.002222	0.0
53	0.007053	JU	0.007053	.31	0.007053	0.0	0.002222	0.0
54	0.007054	JU	0.007054	.31	0.007054	0.0	0.002222	0.0
55	0.007055	JU	0.007055	.31	0.007055	0.0	0.002222	0.0
56	0.007056	JU	0.007056	.31	0.007056	0.0	0.002222	0.0
57	0.007057	JU	0.007057	.31	0.007057	0.0	0.002222	0.0
58	0.007058	JU	0.007058	.31	0.007058	0.0	0.002222	0.0
59	0.007059	JU	0.007059	.31	0.007059	0.0	0.002222	0.0
60	0.007060	JU	0.007060	.31	0.007060	0.0	0.002222	0.0
61	0.007061	JU	0.007061	.31	0.007061	0.0	0.002222	0.0
62	0.007062	JU	0.007062	.31	0.007062	0.0	0.002222	0.0
63	0.007063	JU	0.007063	.31	0.007063	0.0	0.002222	0.0
64	0.007064	JU	0.007064	.31	0.007064	0.0	0.002222	0.0
65	0.007065	JU	0.007065	.31	0.007065	0.0	0.002222	0.0
66	0.007066	JU	0.007066	.31	0.007066	0.0	0.002222	0.0
67	0.007067	JU	0.007067	.31	0.007067	0.0	0.002222	0.0
68	0.007068	JU	0.007068	.31	0.007068	0.0	0.002222	0.0
69	0.007069	JU	0.007069	.31	0.007069	0.0	0.002222	0.0
70	0.007070	JU	0.007070	.31	0.007070	0.0	0.002222	0.0
71	0.007071	JU	0.007071	.31	0.007071	0.0	0.002222	0.0
72	0.007072	JU	0.007072	.31	0.007072	0.0	0.002222	0.0
73	0.007073	JU	0.007073	.31	0.007073	0.0	0.002222	0.0
74	0.007074	JU	0.007074	.31	0.007074	0.0	0.002222	0.0
75	0.007075	JU	0.007075	.31	0.007075	0.0	0.002222	0.0
76	0.007076	JU	0.007076	.31	0.007076	0.0	0.002222	0.0
77	0.007077	JU	0.007077	.31	0.007077	0.0	0.002222	0.0
78	0.007078	JU	0.007078	.31	0.007078	0.0	0.002222	0.0
79	0.007079	JU	0.007079	.31	0.007079	0.0	0.002222	0.0
80	0.007080	JU	0.007080	.31	0.007080	0.0	0.002222	0.0
81	0.007081	JU	0.007081	.31	0.007081	0.0	0.002222	0.0
82	0.007082	JU	0.007082	.31	0.007082	0.0	0.002222	0.0
83	0.007083	JU	0.007083	.31	0.007083	0.0	0.002222	0.0
84	0.007084	JU	0.007084	.31	0.007084	0.0	0.002222	0.0
85	0.007085	JU	0.007085	.31	0.007085	0.0	0.002222	0.0
86	0.007086	JU	0.007086	.31	0.007086	0.0	0.002222	0.0
87	0.007087	JU	0.007087	.31	0.007087	0.0	0.002222	0.0
88	0.007088	JU	0.007088	.31	0.007088	0.0	0.002222	0.0
89	0.007089	JU	0.007089	.31	0.007089	0.0	0.002222	0.0
90	0.007090	JU	0.007090	.31	0.007090	0.0	0.002222	0.0
91	0.007091	JU	0.007091	.31	0.007091	0.0	0.002222	0.0
92	0.007092	JU	0.007092	.31	0.007092	0.0	0.002222	0.0
93	0.007093	JU	0.007093	.31	0.007093	0.0	0.002222	0.0
94	0.007094	JU	0.007094	.31	0.007094	0.0	0.002222	0.0
95	0.007095	JU	0.007095	.31	0.007095	0.0	0.002222	0.0
96	0.007096	JU	0.007096	.31	0.007096	0.0	0.002222	0.0
97	0.007097	JU	0.007097	.31	0.007097	0.0	0.002222	0.0
98	0.007098	JU	0.007098	.31	0.007098	0.0	0.002222	0.0
99	0.007099	JU	0.007099	.31	0.007099	0.0	0.002222	0.0
100	0.007100	JU	0.007100	.31	0.007100	0.0	0.002222	0.0
101	0.007101	JU	0.007101	.31	0.007101	0.0	0.002222	0.0
102	0.007102	JU	0.007102	.31	0.007102	0.0	0.002222	0.0
103	0.007103	JU	0.007103	.31	0.007103	0.0	0.002222	0.0
104	0.007104	JU	0.007104	.31	0.007104	0.0	0.002222	0.0
105	0.007105	JU	0.007105	.31	0.007105	0.0	0.002222	0.0
106	0.007106	JU	0.007106	.31	0.007106	0.0	0.002222	0.0
107	0.007107	JU	0.007107	.31	0.007107	0.0	0.002222	0.0
108	0.007108	JU	0.007108	.31	0.007108	0.0	0.002222	0.0
109	0.007109	JU	0.007109	.31	0.007109	0.0	0.002222	0.0
110	0.007110	JU	0.007110	.31	0.007110	0.0	0.002222	0.0
111	0.007111	JU	0.007111	.31	0.007111	0.0	0.002222	0.0
112	0.007112	JU	0.007112	.31	0.007112	0.0	0.002222	0.0
113	0.007113	JU	0.007113	.31	0.007113	0.0	0.002222	0.0
114	0.007114	JU	0.007114	.31	0.007114	0.0	0.002222	0.0
115	0.007115	JU	0.007115	.31	0.007115	0.0	0.002222	0.0
116	0.007116	JU	0.007116	.31	0.007116	0.0	0.002222	0.0
117	0.007117	JU	0.007117	.31	0.007117	0.0	0.002222	0.0
118	0.007118	JU	0.007118	.31	0.0			

~~DO NOT USE COPY~~

CHARGE MU. = 30.1 MM. 40 DEGREE. 1,160 MM WALL. COPPER LINES

ALL VALUES ARE THE AVERAGE FROM THREE RADIOSCAPHS

NU.	VELOCITY MM/MICROSEC.	SU TIME MICROSEC.	LENGTH MM.	DIAMETER MM.	RADIUS MM.	L/D RATIO	VEL CHANGE
1	2.031023E+01	6.70674E-01	7.12533E-01	1.06167E-01	2.031023E-01	6.55945E-01	1.30445E-01
2	2.01012E+01	6.84925E-01	6.84925E-01	1.36503E-01	2.01012E-01	6.77778E-01	6.06666E-01
3	2.00720E+01	6.90732E-01	6.90732E-01	1.38500E-01	2.00720E-01	6.77774E-01	1.42024E-01
4	1.99432E+01	7.03573E-01	7.03573E-01	1.21335E-01	6.06667E-01	8.31333E-01	7.16935E-02
5	1.99034E+01	7.04927E-01	7.04933E-01	1.06083E-01	5.94167E-01	5.72222E-01	1.60812E-01
6	1.98723E+01	7.05646E-01	7.05646E-01	1.05166E-01	7.54167E-01	4.30576E-01	1.43920E-01
7	1.98416E+01	7.04291E-01	7.05061E-01	1.05883E-01	5.34167E-01	5.90896E-01	1.65268E-01
8	1.98103E+01	7.03933E-01	7.03933E-01	1.05166E-01	7.54167E-01	5.05556E-01	1.19197E-01
9	1.97792E+01	7.03576E-01	7.03576E-01	1.05166E-01	7.54167E-01	5.05556E-01	1.19197E-01
10	1.97482E+01	7.03239E-01	7.03239E-01	1.05166E-01	7.54167E-01	5.05556E-01	1.19197E-01
11	1.97169E+01	7.02902E-01	7.02902E-01	1.05083E-01	7.54167E-01	5.13689E-01	8.21394E-02
12	1.96852E+01	7.02575E-01	7.02575E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
13	1.96536E+01	7.02239E-01	7.02239E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
14	1.96219E+01	7.01902E-01	7.01902E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
15	1.95892E+01	7.01565E-01	7.01565E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
16	1.95565E+01	7.01228E-01	7.01228E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
17	1.95237E+01	7.00891E-01	7.00891E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
18	1.94909E+01	7.00554E-01	7.00554E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
19	1.94582E+01	7.00217E-01	7.00217E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
20	1.94254E+01	6.99880E-01	6.99880E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
21	1.93927E+01	6.99543E-01	6.99543E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
22	1.93599E+01	6.99206E-01	6.99206E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
23	1.93272E+01	6.98869E-01	6.98869E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
24	1.92944E+01	6.98532E-01	6.98532E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
25	1.92617E+01	6.98195E-01	6.98195E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
26	1.92290E+01	6.97858E-01	6.97858E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
27	1.91963E+01	6.97521E-01	6.97521E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
28	1.91635E+01	6.97184E-01	6.97184E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
29	1.91308E+01	6.96847E-01	6.96847E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
30	1.90981E+01	6.96510E-01	6.96510E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
31	1.90654E+01	6.96173E-01	6.96173E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
32	1.90327E+01	6.95836E-01	6.95836E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
33	1.90000E+01	6.95499E-01	6.95499E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
34	1.89673E+01	6.95162E-01	6.95162E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
35	1.89346E+01	6.94825E-01	6.94825E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
36	1.89019E+01	6.94488E-01	6.94488E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
37	1.88692E+01	6.94151E-01	6.94151E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
38	1.88365E+01	6.93814E-01	6.93814E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
39	1.88038E+01	6.93477E-01	6.93477E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
40	1.87711E+01	6.93140E-01	6.93140E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
41	1.87384E+01	6.92773E-01	6.92773E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
42	1.87057E+01	6.92436E-01	6.92436E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
43	1.86730E+01	6.92099E-01	6.92099E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
44	1.86403E+01	6.91762E-01	6.91762E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
45	1.86076E+01	6.91425E-01	6.91425E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
46	1.85749E+01	6.91088E-01	6.91088E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
47	1.85422E+01	6.90751E-01	6.90751E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
48	1.85095E+01	6.90414E-01	6.90414E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
49	1.84768E+01	6.90077E-01	6.90077E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
50	1.84441E+01	6.89740E-01	6.89740E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
51	1.84114E+01	6.89403E-01	6.89403E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
52	1.83787E+01	6.89066E-01	6.89066E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
53	1.83460E+01	6.88730E-01	6.88730E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
54	1.83133E+01	6.88393E-01	6.88393E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
55	1.82806E+01	6.88056E-01	6.88056E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
56	1.82479E+01	6.87720E-01	6.87720E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
57	1.82152E+01	6.87383E-01	6.87383E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
58	1.81825E+01	6.87046E-01	6.87046E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
59	1.81498E+01	6.86710E-01	6.86710E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
60	1.81171E+01	6.86373E-01	6.86373E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
61	1.80844E+01	6.86036E-01	6.86036E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
62	1.80517E+01	6.85700E-01	6.85700E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
63	1.80190E+01	6.85363E-01	6.85363E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
64	1.79863E+01	6.85026E-01	6.85026E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
65	1.79536E+01	6.84689E-01	6.84689E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
66	1.79209E+01	6.84352E-01	6.84352E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
67	1.78882E+01	6.83915E-01	6.83915E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
68	1.78555E+01	6.83578E-01	6.83578E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
69	1.78228E+01	6.83241E-01	6.83241E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
70	1.77891E+01	6.82904E-01	6.82904E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
71	1.77564E+01	6.82567E-01	6.82567E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
72	1.77237E+01	6.82230E-01	6.82230E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
73	1.76910E+01	6.81893E-01	6.81893E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
74	1.76583E+01	6.81556E-01	6.81556E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
75	1.76256E+01	6.81219E-01	6.81219E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
76	1.75929E+01	6.80882E-01	6.80882E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
77	1.75592E+01	6.80545E-01	6.80545E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
78	1.75265E+01	6.80208E-01	6.80208E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
79	1.74938E+01	6.79871E-01	6.79871E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
80	1.74611E+01	6.79534E-01	6.79534E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
81	1.74284E+01	6.79197E-01	6.79197E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
82	1.73957E+01	6.78860E-01	6.78860E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
83	1.73630E+01	6.78523E-01	6.78523E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
84	1.73293E+01	6.78186E-01	6.78186E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
85	1.72966E+01	6.77849E-01	6.77849E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
86	1.72639E+01	6.77512E-01	6.77512E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
87	1.72312E+01	6.77175E-01	6.77175E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-02
88	1.71985E+01	6.76838E-01	6.76838E-01	1.05083E-01	7.54167E-01	5.13689E-01	9.27031E-0

CHAMFERED MUS. 20.0 MM. 42 DEGREES + 0.0762 MM. WALL. CUPPED LINER  
HOLE VALUES AND THE AVERAGE FINGERS THICKNESS

NU.	INFLUENCY	MACHINERY	TIME	MICROSEC.	DISTANCE		LENGTH	RADIIUS	L/U RATIO
					M	μ			
1	0.47053	JU	1.00000E-02	0.20000E-02	0.0	0.20000E-02	0.0	0.00000E+00	7.71282E-09
2	0.49303	JU	2.00000E-02	0.10000E-02	0.0	0.00000E+00	0.0	5.55555E-09	4.27774E-09
3	0.49303	JU	3.00000E-02	0.05000E-02	0.0	0.00000E+00	0.0	2.66667E-09	4.27774E-09
4	0.49303	JU	4.00000E-02	0.02500E-02	0.0	0.00000E+00	0.0	1.45000E-09	4.27774E-09
5	0.49303	JU	5.00000E-02	0.01250E-02	0.0	0.00000E+00	0.0	0.66667E-09	4.27774E-09
6	0.49303	JU	6.00000E-02	0.00625E-02	0.0	0.00000E+00	0.0	0.33333E-09	4.27774E-09
7	0.49303	JU	7.00000E-02	0.003125E-02	0.0	0.00000E+00	0.0	0.16667E-09	4.27774E-09
8	0.49303	JU	8.00000E-02	0.0015625E-02	0.0	0.00000E+00	0.0	0.08333E-09	4.27774E-09
9	0.49303	JU	9.00000E-02	0.00078125E-02	0.0	0.00000E+00	0.0	0.04167E-09	4.27774E-09
10	0.49303	JU	1.00000E-01	0.000390625E-02	0.0	0.00000E+00	0.0	0.02083E-09	4.27774E-09
11	0.49303	JU	1.10000E-01	0.0001953125E-02	0.0	0.00000E+00	0.0	0.010416E-09	4.27774E-09
12	0.49303	JU	1.20000E-01	0.00009765625E-02	0.0	0.00000E+00	0.0	0.005208E-09	4.27774E-09
13	0.49303	JU	1.30000E-01	0.000048828125E-02	0.0	0.00000E+00	0.0	0.002604E-09	4.27774E-09
14	0.49303	JU	1.40000E-01	0.0000244140625E-02	0.0	0.00000E+00	0.0	0.001302E-09	4.27774E-09
15	0.49303	JU	1.50000E-01	0.00001220703125E-02	0.0	0.00000E+00	0.0	0.000651E-09	4.27774E-09
16	0.49303	JU	1.60000E-01	0.000006103515625E-02	0.0	0.00000E+00	0.0	0.000325E-09	4.27774E-09
17	0.49303	JU	1.70000E-01	0.0000030517578125E-02	0.0	0.00000E+00	0.0	0.0001625E-09	4.27774E-09
18	0.49303	JU	1.80000E-01	0.00000152587890625E-02	0.0	0.00000E+00	0.0	0.00008125E-09	4.27774E-09
19	0.49303	JU	1.90000E-01	0.000000762939453125E-02	0.0	0.00000E+00	0.0	0.000040625E-09	4.27774E-09
20	0.49303	JU	2.00000E-01	0.0000003814697265625E-02	0.0	0.00000E+00	0.0	0.0000203125E-09	4.27774E-09
21	0.49303	JU	2.10000E-01	0.00000019073486328125E-02	0.0	0.00000E+00	0.0	0.00001015625E-09	4.27774E-09
22	0.49303	JU	2.20000E-01	0.000000095367431640625E-02	0.0	0.00000E+00	0.0	0.000005078125E-09	4.27774E-09
23	0.49303	JU	2.30000E-01	0.0000000476837158203125E-02	0.0	0.00000E+00	0.0	0.0000025390625E-09	4.27774E-09
24	0.49303	JU	2.40000E-01	0.00000002384185791015625E-02	0.0	0.00000E+00	0.0	0.00000126953125E-09	4.27774E-09
25	0.49303	JU	2.50000E-01	0.000000012020928955078125E-02	0.0	0.00000E+00	0.0	0.000000634765625E-09	4.27774E-09
26	0.49303	JU	2.60000E-01	0.0000000060104644775390625E-02	0.0	0.00000E+00	0.0	0.00000031738125E-09	4.27774E-09
27	0.49303	JU	2.70000E-01	0.00000000300523223876953125E-02	0.0	0.00000E+00	0.0	0.000000158690625E-09	4.27774E-09
28	0.49303	JU	2.80000E-01	0.000000001502616119384765625E-02	0.0	0.00000E+00	0.0	0.0000000793453125E-09	4.27774E-09
29	0.49303	JU	2.90000E-01	0.00000000075130805969238125E-02	0.0	0.00000E+00	0.0	0.00000003967265625E-09	4.27774E-09
30	0.49303	JU	3.00000E-01	0.0000000003756540298461953125E-02	0.0	0.00000E+00	0.0	0.000000019836328125E-09	4.27774E-09
31	0.49303	JU	3.10000E-01	0.00000000018782701492309765625E-02	0.0	0.00000E+00	0.0	0.0000000099181640625E-09	4.27774E-09
32	0.49303	JU	3.20000E-01	0.000000000093913507461548828125E-02	0.0	0.00000E+00	0.0	0.00000000495908203125E-09	4.27774E-09
33	0.49303	JU	3.30000E-01	0.00000000004695675373077443828125E-02	0.0	0.00000E+00	0.0	0.000000002479541015625E-09	4.27774E-09
34	0.49303	JU	3.40000E-01	0.000000000023478376865387221875E-02	0.0	0.00000E+00	0.0	0.0000000012397705078125E-09	4.27774E-09
35	0.49303	JU	3.50000E-01	0.0000000000117391884326936109375E-02	0.0	0.00000E+00	0.0	0.00000000061988525390625E-09	4.27774E-09
36	0.49303	JU	3.60000E-01	0.0000000000586959421634680547875E-02	0.0	0.00000E+00	0.0	0.0000000003094926265625E-09	4.27774E-09
37	0.49303	JU	3.70000E-01	0.00000000002934797108173402389375E-02	0.0	0.00000E+00	0.0	0.0000000015474631328125E-09	4.27774E-09
38	0.49303	JU	3.80000E-01	0.000000000014673985540867011946875E-02	0.0	0.00000E+00	0.0	0.0000000007737315640625E-09	4.27774E-09
39	0.49303	JU	3.90000E-01	0.0000000000733699277043350597234375E-02	0.0	0.00000E+00	0.0	0.00000000038686978203125E-09	4.27774E-09
40	0.49303	JU	4.00000E-01	0.00000000003668496385216752961171875E-02	0.0	0.00000E+00	0.0	0.000000000193429891015625E-09	4.27774E-09
41	0.49303	JU	4.10000E-01	0.000000000018334981926083764805589375E-02	0.0	0.00000E+00	0.0	0.00000000009671494953125E-09	4.27774E-09
42	0.49303	JU	4.20000E-01	0.000000000009167490963041882402774375E-02	0.0	0.00000E+00	0.0	0.000000000048357474765625E-09	4.27774E-09
43	0.49303	JU	4.30000E-01	0.00000000000458374548152094120138675E-02	0.0	0.00000E+00	0.0	0.00000000002417873238125E-09	4.27774E-09
44	0.49303	JU	4.40000E-01	0.0000000000022918727407604706006934375E-02	0.0	0.00000E+00	0.0	0.0000000000120893661953125E-09	4.27774E-09
45	0.49303	JU	4.50000E-01	0.00000000000114593637038023530034671875E-02	0.0	0.00000E+00	0.0	0.00000000000604468309765625E-09	4.27774E-09
46	0.49303	JU	4.60000E-01	0.0000000000057296818519001176001734375E-02	0.0	0.00000E+00	0.0	0.0000000000030222791984375E-09	4.27774E-09
47	0.49303	JU	4.70000E-01	0.00000000000286484092595005880008671875E-02	0.0	0.00000E+00	0.0	0.0000000000151103959921875E-09	4.27774E-09
48	0.49303	JU	4.80000E-01	0.000000000001432420462975029400043375E-02	0.0	0.00000E+00	0.0	0.0000000000075551969765625E-09	4.27774E-09
49	0.49303	JU	4.90000E-01	0.000000000007162102314875014700021875E-02	0.0	0.00000E+00	0.0	0.00000000000377709848828125E-09	4.27774E-09
50	0.49303	JU	5.00000E-01	0.0000000000035810511574375073500109375E-02	0.0	0.00000E+00	0.0	0.0000000000018855250744140625E-09	4.27774E-09
51	0.49303	JU	5.10000E-01	0.00000000000179052557871875367500546875E-02	0.0	0.00000E+00	0.0	0.0000000000094276253721875E-09	4.27774E-09
52	0.49303	JU	5.20000E-01	0.000000000008952627893593768387502734375E-02	0.0	0.00000E+00	0.0	0.0000000000047388139684375E-09	4.27774E-09
53	0.49303	JU	5.30000E-01	0.000000000004476313946796884193751375E-02	0.0	0.00000E+00	0.0	0.000000000002369166984375E-09	4.27774E-09
54	0.49303	JU	5.40000E-01	0.000000000002238156973498442093750675E-02	0.0	0.00000E+00	0.0	0.00000000000118457848734375E-09	4.27774E-09
55	0.49303	JU	5.50000E-01	0.00000000000111907848674922104687503125E-02	0.0	0.00000E+00	0.0	0.00000000000594739244375E-09	4.27774E-09
56	0.49303	JU	5.60000E-01	0.0000000000055953924437501105234375E-02	0.0	0.00000E+00	0.0	0.000000000002977696221875E-09	4.27774E-09
57	0.49303	JU	5.70000E-01	0.000000000002797696110875055260375E-02	0.0	0.00000E+00	0.0	0.0000000000014888480546875E-09	4.27774E-09
58	0.49303	JU	5.80000E-01	0.000000000001398848054687527630375E-02	0.0	0.00000E+00	0.0	0.0000000000074442402734375E-09	4.27774E-09
59	0.49303	JU	5.90000E-01	0.000000000006994240273437513815375E-02	0.0	0.00000E+00	0.0	0.0000000000037471171875E-09	4.27774E-09
60	0.49303	JU	6.00000E-01	0.00000000000349711718750895075375E-02	0.0	0.00000E+00	0.0	0.00000000000187355853984375E-09	4.27774E-09
61	0.49303	JU	6.10000E-01	0.000000000001748558539843752476875E-02	0.0	0.00000E+00	0.0	0.00000000000093777921875E-09	4.27774E-09
62	0.49303	JU	6.20000E-01	0.000000000008742791599218751239875E-02	0.0	0.00000E+00	0.0	0.00000000000468639609375E-09	4.27774E-09
63	0.49303	JU	6.30000E-01	0.000000000004371396093750449639875E-02	0.0	0.00000E+00	0.0	0.0000000000023456993046875E-09	4.27774E-09
64	0.49303	JU	6.40000E-01	0.000000000002185699304687522481875E-02	0.0	0.00000E+00	0.0	0.00000000000117284965234375E-09	4.27774E-09
65	0.49303	JU	6.50000E-01	0.0000000000010928496523437511240875E-02	0.0	0.00000E+00	0.0	0.000000000005864226828125E-09	4.27774E-09
66	0.49303	JU	6.60000E-01	0.0000000000054642268281250560120875E-02	0.0	0.00000E+00	0.0	0.0000000000027321134375E-09	4.27774E-09
67	0.49303	JU	6.70000E-01	0.000000000002732113437512780060875E-02	0.0	0.00000E+00	0.0	0.000000000001366056903125E-09	4.27774E-09
68	0.49303	JU	6.80000E-01	0.0000000000013660569031250690030875E-02	0.0	0.00000E+00	0.0	0.00000000000683027953125E-09	4.27774E-09
69	0.49303	JU	6.90000E-01	0.0000000000068302795312503450150875E-02	0.0	0.00000E+00	0.0	0.000000000003415139765625E-09	4.27774E-09
70	0.49303	JU	7.00000E-01	0.0000000000034151397656250175075875E-02	0.0	0.00000E+00	0.0	0.0000000000017075798828125E-09	4.27774E-09
71	0.49303	JU	7.10000E-01	0.0000000000017075798828125008755875E-02	0.0	0.00000E+00	0.0	0.0000000000085378994140625E-09	4.27774E-09
72	0.49303	JU	7.20000E-01	0.0000000000008537899414062500437875E-02	0.0	0.00000E+00	0.0	0.00000000000426894970744140625E-09	4.27774E-09
73	0.49303	JU	7.30000E-01	0.0000000000004268949707441406250021875E-02	0.0	0.00000E+00	0.0	0.000000000002134474853984375E-09	4.27774E-09
74	0.49303	JU	7.40000E-01	0.00000000000021344748539843750104375E-02	0.0	0.00000E+00	0.0	0.000000000001067237421875E-09	4.27774E-09
75	0								

三

卷之三

LITERATURE AND THE ARTS IN THE UNITED STATES

卷之三

row#	entity	parent	link	attribute	value		status	last update
					val	unit		
1	1	1	1	1	1	1	1	1
2	2	1	2	2	2	2	2	2
3	3	1	3	3	3	3	3	3
4	4	1	4	4	4	4	4	4
5	5	1	5	5	5	5	5	5
6	6	1	6	6	6	6	6	6
7	7	1	7	7	7	7	7	7
8	8	1	8	8	8	8	8	8
9	9	1	9	9	9	9	9	9
10	10	1	10	10	10	10	10	10
11	11	1	11	11	11	11	11	11
12	12	1	12	12	12	12	12	12
13	13	1	13	13	13	13	13	13
14	14	1	14	14	14	14	14	14
15	15	1	15	15	15	15	15	15
16	16	1	16	16	16	16	16	16
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66	66	1	66	66	66	66	66	66
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72	72	1	72	72	72	72	72	72
73	73	1	73	73	73	73	73	73
74	74	1	74	74	74	74	74	74
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79	79	1	79	79	79	79	79	79
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116	116	1	116	116	116	116	116	116
117	117	1	117	117	117	117	117	117
118	118	1	118	118	118	118	118	118
119	119	1	119	119	119	119	119	119
120	120	1	120	120	120	120	120	120
121	121	1	121	121	121	121	121	121
122	122	1	122	122	122	122	122	122
123	123	1	123	123	123	123	123	123
124	124	1	124	124	124	124	124	124
125	125	1	125	125	125	125	125	125
126	126	1	126	126	126	126	126	126
127	127	1	127	127	127	127	127	127
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129	129	1	129	129	129	129	129	129
130	130	1	130	130	130	130	130	130
131	131	1	131	131	131	131	131	131
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166	166	1	166	166	166	166	166	166
167	167	1	167	167	167	167	167	167
168	168	1	168	168	168	168	168	168
169	169	1	169	169	169	169	169	169
170	170	1	170	170	170	170	170	170
171	171	1	171	171	171	171	171	171
172	172	1	172	172	172	172	172	1

CHAMBER NO. 7 25.0 42 INCHES 200 MM WALL CUPRUM LINE  
ALL VALUES ARE THE AVERAGE FROM THREE MEASUREMENTS

NO.	RELATIVE THICKNESS IN/MILLIMETER	TIME MINUTES	TEMPERATURE KELVIN	DIA. METERS MM.	MAJUS MM.	L/D RATIO	VEL. CHANGE
1	0.56201	00	1.07054	0.1	0.22000	0.0	1.06052E+00
2	0.60911	00	1.09151	0.1	0.22000	0.0	1.023510E+00
3	0.520694	00	0.161025	0.1	0.22000	0.0	1.12302E+01
4	0.474691	00	1.024575	0.1	0.22000	0.0	2.39156E+01
5	0.233521	00	0.603411	0.1	0.22000	0.0	1.23502E+01
6	0.616231	00	1.050575	0.1	0.22000	0.0	1.08653E+01
7	2.403961	00	0.437395	0.1	0.22000	0.0	1.00012E+01
8	2.927101	00	0.111345	0.1	0.22000	0.0	1.00504E+01
9	2.020301	00	0.956495	0.1	0.22000	0.0	4.35521E+02
10	2.043261	00	0.331105	0.1	0.22000	0.0	1.96456E+01
11	2.286671	00	0.059555	0.1	0.22000	0.0	7.91019E+02
12	2.400771	00	0.461625	0.1	0.22000	0.0	7.81119E+02
13	2.324071	00	0.413775	0.1	0.22000	0.0	1.06303E+01
14	2.222261	00	0.861545	0.1	0.22000	0.0	2.24005E+02
15	2.159461	00	7.44205	0.1	0.22000	0.0	1.18652E+01
16	2.001011	00	7.417115	0.1	0.22000	0.0	1.04414E+01
17	2.019011	00	0.671475	0.1	0.22000	0.0	1.06252E+01
18	2.370401	00	1.641135	0.1	0.22000	0.0	1.45903E+01
19	2.084201	00	1.057125	0.1	0.22000	0.0	1.07666E+02
20	2.202211	00	6.427621	0.1	0.22000	0.0	7.87014E+02
21	2.442521	00	1.061051	0.1	0.22000	0.0	1.45004E+01
22	2.315721	00	0.716695	0.1	0.22000	0.0	1.78906E+01
23	4.130491	00	9.166241	0.1	0.22000	0.0	1.04502E+01
24	4.091691	00	9.726195	0.1	0.22000	0.0	1.17752E+01
25	3.964341	00	0.111357	0.1	0.22000	0.0	2.11041E+01
26	3.773301	00	7.641445	0.1	0.22000	0.0	1.27103E+01
27	3.954701	00	6.280065	0.1	0.22000	0.0	2.27002E+02
28	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
29	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
30	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
31	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
32	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
33	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
34	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
35	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
36	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
37	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
38	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
39	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
40	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
41	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
42	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
43	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
44	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
45	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
46	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
47	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
48	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
49	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
50	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
51	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
52	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
53	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
54	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
55	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
56	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
57	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
58	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
59	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
60	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
61	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
62	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
63	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
64	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
65	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
66	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
67	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
68	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
69	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
70	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
71	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
72	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
73	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
74	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
75	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
76	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
77	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
78	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
79	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
80	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
81	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
82	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
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84	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
85	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
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87	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
88	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
89	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
90	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
91	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
92	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
93	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
94	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
95	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
96	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
97	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
98	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
99	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
100	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
101	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
102	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
103	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
104	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
105	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
106	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
107	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
108	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
109	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
110	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
111	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
112	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
113	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
114	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
115	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
116	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
117	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
118	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
119	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
120	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
121	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
122	3.627361	00	1.141041	0.1	0.22000	0.0	1.44115E+02
123	3.627361	00</					

## CHARGE HU. 8. 81.3 MM, 42 DEGREE, TAPED WALL, CUPPER LINER

ALL VALUES ARE THE AVERAGE FROM THREE RADUGRAPHS

NU.	VELOCITY MM/MICROSEC.	BUTIME MICROSEC.	LENGTH MM.	DIAETER MM.	RADIUS MM.	L/D RATIO	VEL CHANGE
1	9.32217E-00	9.96025E-01	2.0.BUG00L 01	9.020000E 00	4.060000E 00	3.05000E 00	6.60566E-02
2	0.25911E-00	9.17165E-01	1.02113J 01	3.06667E 00	1.53333L 00	3.9032E 00	1.09517E-01
3	0.08959E-00	9.17225E-01	1.22667L 01	3.52667E 00	1.76333L 00	3.4905E 00	2.79164E-02
4	0.04616E-00	9.00950E-02	2.0.BUG00L 00	1.84000E 00	9.20000L 01	1.41667E 00	6.76276E-02
5	7.97403E-00	9.71105E-01	2.14667E-00	2.78000E 00	1.30000E 00	6.22222E-01	4.50967E-02
6	7.42564E-00	9.50500E-01	8.50000E-00	3.68000L 00	1.04000E 00	2.34322E 00	9.55444E-02
7	7.08346E-00	1.04901E-02	5.02667L 00	3.06667E 00	1.53333L 00	1.91276E 00	1.09101E-01
8	7.07314E-00	0.73770E-01	8.12667E-00	3.22000E 00	1.61000L 00	2.62463E 00	1.00304E-01
9	7.06154E-00	1.25614E-02	7.02000E 00	2.91333L 00	1.45667L 00	2.68224E 00	6.22516E-02
10	7.02647E-00	7.65460E-01	5.06000J 00	3.22000E 00	1.61000L 00	1.57736E 00	3.07112E-02
11	7.02496E-00	1.59931E-02	3.0.Y0B07L 00	1.44331L 00	9.66667L 01	2.00000E 00	7.32816E-02
12	7.04542E-00	1.08039E-02	1.027733E 01	2.91333E 00	1.45667L 00	3.60952E 00	1.01962E-01
13	7.03333E-00	1.11340E-02	6.04000U 00	2.45333E 00	1.22667L 00	2.69444E 00	9.00074E-02
14	7.02542E-00	1.05266E-02	5.43333L 00	2.45333E 00	1.22667L 00	3.05333E 00	3.20834E-01
15	7.01229E-00	0.50644E-01	9.81333E 00	2.76000E 00	1.30000L 00	3.05556E 00	7.07517E-02
16	7.04475E-00	1.01053E-02	7.20B667L 00	2.30000E 00	1.15000L 00	3.21111E 00	1.00022E-01
17	6.98725E-00	7.55770E-01	1.11933E 01	3.06667E 00	1.73333L 00	3.74643E 00	5.79274E-02
18	6.98216E-00	1.00323E-02	8.25000U 00	2.76000L 00	1.30000U 00	3.02381E 00	1.55180E-01
19	6.98044E-00	7.08533E-01	3.0.BUG00L 00	3.06667L 00	1.23333L 00	3.04952E 00	1.30495E-01
20	6.95044E-00	1.14702E-02	8.12667L 00	2.60000L 00	1.30000L 00	3.14666E 00	1.53639E-01
21	6.95243E-00	0.57636E-01	6.52333E 00	2.76000E 00	1.30000L 00	2.30466E 00	9.17410E-02
22	6.92496E-00	0.91117E-01	7.36000U 00	2.30000E 00	1.15000E 00	3.20899E 00	1.10610E-01
23	6.91720E-00	0.88883E-01	7.05333E 00	2.30000E 00	1.15000E 00	3.13333E 00	1.021377E-01
24	6.90427E-00	1.04985E-02	1.02400L 01	2.00000E 00	1.15000E 00	5.00000E 00	1.07402E-01
25	6.89722E-00	1.13200E-02	1.20B667L 01	1.93333L 00	1.06666L 01	6.55000E 00	7.24778E-02
26	6.86479E-00	0.75200E-01	9.00000U 00	2.14666L 00	1.07333L 00	2.16667E 00	1.06526E-01
27	6.81422E-00	1.03847E-02	7.05333E 00	1.99333L 00	0.96666PL 01	3.566667E 00	9.78708E-02
28	6.73103E-00	1.29410E-02	3.97333E 00	1.84000E 00	2.00000E 01	1.63333E 00	1.012135E-02
29	6.700423E-00	1.06790E-02	9.50666L 00	1.93333E 00	1.06666L 01	4.31667E 00	2.77453E-01
30	6.05455E-01	3.05455E-01	1.22733E 01	1.93333E 00	1.06666L 01	6.46333E 00	2.01014E-02
31	7.43049E-01	7.43049E-01	3.22000U 00	1.07333E 00	5.36666L 01	3.11111E 00	7.99661E-02
32	7.11572E-00	1.06659E-02	9.98000L 00	2.30000L 00	1.15000L 00	4.46666E 00	1.78246E-01
33	6.93748E-00	1.00099E-02	1.272667L 01	2.14666L 00	1.07333L 00	6.000095E 00	1.51990E-01
34	6.01249E-01	1.01249E-02	1.04266L 01	2.14666L 00	1.07333L 00	6.900095E 00	1.52424E-01
35	1.02620E-01	1.02620E-02	9.50666L 00	1.99333L 00	0.96666PL 01	5.06666E 00	7.046778E-02
36	4.03849E-01	7.03849E-02	7.02000U 00	1.46666L 00	1.09333L 00	3.17897E 00	1.00000E-01
							1.07937E-01
							1.31249E 00
							1.34360E 00
							2.08879E 00
							6.49809E 01
							1.30109E 00
							5.977749E-02
							9.10990E-01

AVERAUL =

Y.76509E 01

0.49809E 00

3.11249E 00

STANDARD DEVIATION

4.07111E-01

CUTT. OF VARIATION

4.010990E-01

CHANNEL NUMBER 50.0 MM. 40 DEGREE, 1.626 MM WALL. ALUMINUM LINER

ALL VALUES ARE THE AVERAGE FROM THREE RAILGRAPHS

COFFEE OF AFRICAN ORIGIN 3-019122-01

## CHANNEL NUMBER 50-8 MM. 60 URGENT. 1000 MM WALL. ALUMINUM LINER

## ALL VALUES ARE THE AVERAGE FROM THREE MEASUREMENTS

NU.	FLUENCY MM/MM²SEC	BU TIME MICROSEC.	LENGTH MM.	DIAMETER MM.	MAULUS MM.	L/D RATIO	V/L CHARGE
1	7.0900E+00	5.0015E+01	1.7676E+01	1.8200E+00	1.1000E+01	9.5033E+00	3.0343E+02
2	7.0487E+01	6.2639E+01	7.0666E+00	1.6200E+00	1.1000E+01	6.3313E+00	2.1014E+01
3	7.0621E+01	7.2311E+01	1.4226E+01	1.8200E+00	1.1000E+01	7.0333E+00	1.9109E+01
4	7.0451E+01	7.0886E+01	1.6200E+00	1.6200E+00	1.1000E+01	2.0082E+01	7.1081E+01
5	7.0444E+01	6.7757E+01	6.6673E+01	1.3050E+00	1.0825E+01	4.8488E+00	7.1081E+01
6	7.1732E+01	6.6264E+01	7.2500E+00	1.6200E+00	1.1000E+01	6.0000E+00	1.9862E+01
7	6.4747E+01	7.2873E+01	7.1283E+00	1.8200E+00	1.1000E+01	7.9146E+00	9.7811E+02
8	6.0570E+01	6.2046E+01	4.1213E+00	1.8200E+00	1.1000E+01	1.1844E+00	9.4007E+02
9	6.0522E+01	6.1842E+01	1.0311E+01	1.6663E+00	1.0316E+01	6.2777E+01	1.1773E+01
10	6.0500E+01	6.0494E+01	7.2101E+00	1.6200E+00	1.1000E+01	5.0455E+01	1.1152E+01
11	6.2554E+01	7.1463E+01	6.0866E+00	1.6200E+00	1.1000E+01	2.4000E+01	2.3400E+01
12	6.1426E+01	7.4903E+01	7.5913E+00	1.6200E+00	1.1000E+01	1.2884E+01	1.1146E+01
13	6.1451E+01	6.4952E+01	1.2740E+01	1.8200E+00	1.1000E+01	7.0000E+00	1.0000E+01
14	6.0661E+01	7.3661E+01	3.3336E+00	1.8200E+00	1.1000E+01	1.8933E+00	1.1923E+01
15	2.9497E+01	6.0147E+01	6.5216E+02	1.6200E+00	1.1000E+01	1.9533E+00	1.0143E+01
16	2.0027E+01	7.6352E+01	1.3360E+01	1.8200E+00	1.1000E+01	7.5000E+03	2.1700E+01
17	2.0060E+01	6.5353E+01	2.3030E+01	1.6200E+00	1.1000E+01	2.4166E+01	5.8000E+02
18	2.5515E+01	6.2703E+01	7.4416E+01	1.6200E+00	1.1000E+01	0.9033E+00	9.0901E+02
19	2.4866E+01	7.0279E+01	2.4666E+01	1.8200E+00	1.1000E+01	3.0000E+01	6.4467E+02
20	2.3947E+01	7.6734E+01	2.4666E+01	1.8200E+00	1.1000E+01	3.0000E+01	1.0000E+01
21	2.0479E+01	1.0787E+02	1.5166E+01	1.6200E+00	1.1000E+01	6.3333E+00	5.4161E+02
22	2.1257E+01	7.1664E+01	1.0766E+01	1.6200E+00	1.1000E+01	3.9166E+00	2.3899E+01
23	4.3594E+01	1.0931E+02	1.2740E+01	1.8200E+00	1.1000E+01	7.0000E+00	1.3740E+01
24	4.7392E+01	7.1592E+01	9.5526E+00	1.6200E+00	1.1000E+01	5.2500E+00	1.5517E+02
25	4.7240E+01	1.0410E+02	1.0970E+01	1.8200E+00	1.1000E+01	6.0000E+00	3.6666E+02
26	4.0673E+01	6.3730E+01	6.3730E+00	1.6200E+00	1.1000E+01	3.5000E+00	1.0000E+01
AV MAULUS =		7.9005E+01	6.0820E+01	1.7496E+01	6.9633E+01	6.4166E+01	1.2934E+01
STANDARD DEVIATION					2.0033E+00	6.0390E+02	
C.I.E.R. OF VARIATION					4.1972E+01	9.2000E+01	

## CHANNEL NO. 11 20.0 MHZ 90 DEGREES 1.025 MM WALL ALUMINUM LINER

## ALL VALUES ARE THE AVERAGE FROM THREE MEASUREMENTS

NO.	VULCANIZING TEMPERATURE	TIME MINUTES	LENGTH MM.	ULTRASONIC MM.	MAJUS MM.	MINUS MM.	L/U RATIO	R/L RATIO
1	0.0512E 00	0.0550E 01	1.020001 00	1.020001 00	0.100001 00	-0.100001 00	1.0750E 01	1.0750E 01
2	0.0143E 00	1.0552E 02	1.020001 00	1.020001 00	0.100001 00	-0.100001 00	1.0750E 01	1.0750E 01
3	0.02015E 00	0.0034E 01	1.020001 00	1.020001 00	0.100001 00	-0.100001 00	1.0750E 01	1.0750E 01
4	0.04957E 00	1.0039E 02	1.020001 00	1.020001 00	0.100001 00	-0.100001 00	1.0750E 01	1.0750E 01
5	0.04717E 00	1.0517E 02	1.020001 00	1.020001 00	0.100001 00	-0.100001 00	1.0750E 01	1.0750E 01
6	0.04639E 00	1.0552E 02	1.020001 00	1.020001 00	0.100001 00	-0.100001 00	1.0750E 01	1.0750E 01
7	0.04703E 00	1.0693E 02	1.020001 00	1.020001 00	0.100001 00	-0.100001 00	1.0750E 01	1.0750E 01
8	0.04703E 00	1.1075E 02	1.020001 00	1.020001 00	0.100001 00	-0.100001 00	1.0750E 01	1.0750E 01
9	0.04639E 00	1.2116E 02	1.020001 00	1.020001 00	0.100001 00	-0.100001 00	1.0750E 01	1.0750E 01
10	0.04639E 00	1.0684E 02	1.020001 00	1.020001 00	0.100001 00	-0.100001 00	1.0750E 01	1.0750E 01
11	0.04639E 00	1.3117E 02	1.020001 00	1.020001 00	0.100001 00	-0.100001 00	1.0750E 01	1.0750E 01
12	0.04639E 00	1.1761E 02	1.020001 00	1.020001 00	0.100001 00	-0.100001 00	1.0750E 01	1.0750E 01
13	0.04639E 00	1.0949E 02	1.020001 00	1.020001 00	0.100001 00	-0.100001 00	1.0750E 01	1.0750E 01
14	0.04717E 00	1.0774E 02	1.020001 00	1.020001 00	0.100001 00	-0.100001 00	1.0750E 01	1.0750E 01
15	0.04717E 00	1.1247E 02	1.020001 00	1.020001 00	0.100001 00	-0.100001 00	1.0750E 01	1.0750E 01

AVERAGE = 1.0750E 01  
STANDARD DEVIATION = 0.0000E 00  
L/EFF + U VARIATION = 0.02630E -01  
L/EFF - U VARIATION = 0.02630E -01STANDARD DEVIATION = 0.0000E 00  
L/EFF + U VARIATION = 0.02630E -01  
L/EFF - U VARIATION = 0.02630E -01